



**Argentina**  
Festo S.A.  
Edison 2392  
(1640) Martínez  
Prov. Buenos Aires  
Ventas y Asistencia técnica  
0810-555-FESTO (33786)  
ventas@ar.festo.com  
Tel. 0810-444-3127, Fax +54 (011) 47 17 82 82  
E-mail: info@ar.festo.com

**Australia**  
Festo Pty. Ltd.  
Head Office (Melbourne)  
179-187 Browns Road  
P.O. Box 261  
Noble Park Vic. 3174  
Tel. +61(0)3 97 95 95 55,  
Fax +61(0)3 97 95 97 87  
E-mail: info\_au@festo.com

**Austria**  
Festo Gesellschaft m.b.H.  
Linzer Straße 227  
1140 Wien  
Tel. +43 (0)1 910 75-0, Fax +43 (0)1 910 75-250  
E-mail: automation@festo.at

**Belarus**  
IP Festo  
Masherov avenue, 78  
220035 Minsk  
Tel. +375 (0)17 204 85 58,  
Fax +375 (0)17 204 85 59  
E-mail: info\_by@festo.com

**Belgium**  
Festo Belgium sa  
Rue Colonel Bourg 101  
1030 Brussel  
Tel. +32 (0)2 702 32 11, Fax +32 (0)2 702 32 09  
E-mail: info\_be@festo.com

**Belgium**  
Festo Belgium nv  
Kolonel Bourgstraat 101  
1030 Bruxelles  
Tel. +32 (0)2 702 32 11, Fax +32 (0)2 702 32 09  
E-mail: info\_be@festo.com

**Brazil**  
Festo Brasil Ltda  
Rua Guiseppe Crespi, 76  
Jd. Santa Emilia  
04183-080 São Paulo / SP -Brasil  
vendas@br.festo.com  
Tel. +55 (11) 5013-1600,  
Fax +55 (11) 5013-1801  
E-mail: linhadijeta@br.festo.com

**Bulgaria**  
Festo EOOD  
1592 Sofia  
Bul. Christophor Kolumb 9  
Tel. +359 (0)2 960 07 12,  
Fax +359 (0)2 960 07 13  
E-mail: info\_bg@festo.com

**Canada**  
Festo Didactic Ltée/Ltd  
675, Rue du Carbone  
Québec, Québec, G2N 2K7  
Tel. +1 (418) 849-1000  
Fax +1 (418) 849-1666  
E-mail: services.didactic@festo.com

**Chile**  
Festo S.A.  
Avenida Américo Vespucio, 760  
Pudahuel  
Santiago  
Tel. +56 (2) 690 28 01, Fax +56 2 690 28 60  
E-mail: info.chile@cl.festo.com

**China**  
Festo (China) Ltd.  
1156 Yunqiao Road,  
Jinqiao Export Processing Zone,  
Pudong,  
Shanghai 201206  
Tel. +86 21 60 81 51 00, Fax +86 21 58 54 03 00  
E-mail: info\_cn@cn.festo.com

**Colombia**  
Festo Ltda.  
Vereda la Punta Autopista MedellínKm6.3 (Costado)  
Tenjo, Cundinamarca  
Tel. +57(1) 865 77 29, Fax +57(1) 865 77 94  
E-mail: mercadeo@co.festo.com

**Croatia**  
Festo d.o.o.  
Nova Cesta 181  
10000 Zagreb  
Tel. +385 (0)1 619 19 69,  
Fax +385 (0)1 619 18 18  
E-mail: info\_hr@festo.com

**Czech Republic**  
Festo, s.r.o.  
Modřanská 543/76  
147 00 Praha 4  
Tel. +420 261 09 96 11, Fax +420 241 77 33 84  
E-mail: info\_cz@festo.com

**Denmark**  
Festo A/S  
Islejvælvej 180  
2610 Rødovre  
Tel. +45 70 21 10 90, Fax +45 44 88 81 10  
E-mail: info\_dk@festo.com

**Estonia**  
Festo OY AB Eesti Filiaal  
A.H. Tammsaare tee 1188  
12918 Tallinn  
Tel. +372 666 1560, Fax +372 666 15 6  
E-mail: info\_ee@festo.com

**Finland**  
Festo Oy  
Mäkituvantie 9  
PL 86  
01511 Vantaa  
Tel. +358 (09) 87 06 51,  
Fax +358 (09) 87 06 52 00  
E-mail: info\_fi@festo.com

**France**  
Festo Eurl  
2A des Maisons Rouges  
8 rue du clos sainte Catherine  
94360 Bry-sur-Marne  
Tel. +33 (0) 820 20 46 40 (numéro indigo),  
Fax +33 (0) 820 20 46 41  
E-mail: info\_fr@festo.com

**Germany**  
Festo Didactic GmbH & Co. KG  
Reichbergstr. 3  
73770 Denkendorf  
Germany  
Tel. +49 (0)711 346 70,  
Fax +49 (0)711 34 75 48 85 00  
E-mail: did@de.festo.com

**Germany**  
Festo AG & Co. KG  
Postfach  
73726 Esslingen  
Ruiter Straße 82  
73734 Esslingen  
Tel. +49 (0) 711 347 0, Fax +49 (0) 711 347 2628  
E-mail: info\_de@festo.com

**Greece**  
Festo Ltd.  
92, Tatoiou Ave.  
P.C. 144 52 Metamorfoosi  
Tel. +30 210 341 29 00 - 4,  
Fax +30 210 341 29 05  
E-mail: info\_gr@festo.com

**Hong Kong**  
Festo Ltd.  
6/F New Timely Factory Building,  
497 Castle Peak Road,  
Kowloon, Hong Kong  
Tel. + 852 27 43 83 79, Fax + 852 27 86 21 73  
E-mail: info\_hk@festo.com

**Hungary**  
Festo Kft.  
Csillaghegyi út 32-34.  
1037 Budapest  
Hotline +36 1 436 51 00  
Tel. +36 1 436 51 11, Fax +36 1 436 51 01  
E-mail: info\_hu@festo.com

**India**  
Festo Controls Private Ltd.  
Festo Controls Pvt. Ltd.  
35/3, Shamanna Garden  
Bannerghatta Road  
Bangalore 560 030  
Tel. +91 (0)1800 425 0036,  
Fax +91 (0)1800 121 0036  
E-mail: sales\_in@festo.com

**Indonesia**  
PT. Festo  
Jl. Tekno V Blok A/1 Sektor XI  
Kawasan Industri BSD  
Serpong - Tangerang 15314  
Banten - Indonesia  
Tel. +62 (0) 21 27 50 79 00,  
Fax +62 (0) 21 27 50 79 98  
E-mail: sales\_id@festo.com

**Iran**  
Festo Pneumatic S.K.  
# 2, 6th street, 16th avenue,  
Km 8, Special Karaj Road  
P.O.Box 15815-1485  
Teheran 1389793761  
Tel. +98 (0)21 44 52 24 09,  
Fax +98 (0)21 44 52 24 08  
E-mail: Mailroom@festo.ir

**Ireland**  
Festo Limited  
Unit 5 Sandyford Park  
Sandyford Industrial Estate  
Dublin 18  
Tel. +353 (0)1 295 49 55,  
Fax +353 (0)1 295 56 80  
E-mail: info\_ie@festo.com

**Israel**  
Festo Pneumatic Israel Ltd.  
P.O. Box 1076  
Ha'atzma'ut Road 48  
Yehud 56100  
Tel. +972 (0)3 632 22 66,  
Fax +972 (0)3 632 22 77  
E-mail: info\_il@festo.com

**Italy**  
Festo SpA  
Via Enrico Fermi 36/38  
20090 Assago (MI)  
Tel. +39 02 45 78 81, Fax +39 02 488 06 20  
E-mail: info\_it@festo.com

**Japan**  
Festo K.K.  
1-26-10 Hayabuchi  
Tsuzuki-ku  
Yokohama 224-0025  
Tel. +81 (0)45 593 5610 / -5611,  
Fax +81 (0)45 593 5678  
E-mail: info\_jp@festo.com

**Korea South**  
Festo Korea Co., Ltd.  
Gasan Digital 1-ro  
Geumcheon-gu  
Seoul #153-803  
Tel. +82 1666 0202, Fax +82 (0)2 864 70 40  
E-mail: sales\_kr@kr.festo.com

**Latvia**  
Festo SIA  
Gunāra Astras 1C  
LV-1084, Rīga  
Tel. +371 67 57 78 64, Fax +371 67 57 79 46  
E-mail: info\_lv@festo.com

**Lithuania**  
Festo, UAB  
Partizanų 63M  
50306 Kaunas  
Lietuva  
Tel. +370 (8)7 32 13 14, Fax +370 (8)7 32 13 15  
E-mail: info\_lt@festo.com

**Malaysia**  
Festo Sdn. Berhad  
10 Persiaran Industri  
Bandar Sri Damansara  
Wilayah Persekutuan  
52200 Kuala Lumpur  
Tel. +60 (0)3 62 86 80 00,  
Fax +60 (0)3 62 75 64 11  
E-mail: info\_my@festo.com

**Mexico**  
Festo Pneumatic, S.A.  
Av. Ceylán 3,  
Col. Tequesquínahuac  
54020 Tlalnepantla  
Estado de México  
Tel. +52 (01)55 53 21 66 00,  
Fax +52 (01)55 53 21 66 55  
E-mail: festo.mexico@mx.festo.com

**Netherlands**  
Festo B.V.  
Schiweg 62  
2627 AN  
Tel. +31 (0)15 251 88 99,  
Fax +31 (0)15 251 88 67  
E-mail: sales@festo.nl

**New Zealand**  
Festo Ltd.  
20 Fisher Crescent  
Mount Wellington  
Auckland  
Tel. +64 (0)9 574 10 94, Fax +64 (0)9 574 10 99  
E-mail: info\_nz@festo.com

**Nigeria**  
Linkou Automation Ltd.  
Motorways Centre, Ground Floor, Block C  
Alausa, Ikeja,  
Lagos  
Tel. +234 (0)1 794 78 20,  
Fax +234 (0)1 555 78 94  
E-mail: info@ng.festo.com

**Norway**  
Festo AS  
Ole Deviks vei 2  
0666 Oslo  
Tel. +47 22 72 89 50, Fax +47 22 72 89 51  
E-mail: info\_no@festo.com

**Peru**  
Festo S.R.L.  
Amador Merino Reyna 480  
San Isidro  
Lima  
Tel. +51 (1) 219 69 60, Fax +51 (1) 219 69 71  
E-mail: festo.peru@pe.festo.com

**Philippines**  
Festo Inc.  
KM 18, West Service Road  
South Super Highway  
1700 Paranaque City  
Metro Manila  
Tel. +63 (2) 77 66 888, Fax +63 (2) 82 34 220/21  
E-mail: info\_ph@festo.com

**Poland**  
Festo Sp. z o.o.  
Janki k/Warszawy  
ul. Mszczonowska 7  
05090 Raszyn  
Tel. +48 (0)22 711 41 00,  
Fax +48 (0)22 711 41 02  
E-mail: info\_pl@festo.com

**Portugal**  
Festo - Automação, Unipessoal, Lda.  
Rua Manuel Pinto De Azevedo, 567  
Apartado 8013  
P-4109601 Porto  
Contact Center: 707 20 20 43  
Tel. +351 22 615 61 50, Fax +351 22 615 61 89  
E-mail: info@pt.festo.com

**Romania**  
Festo S.R.L.  
St. Constantin 17  
010127 Bucuresti  
Tel. +40(0)21 403 95 00,  
Fax +40 (0)21 310 24 09  
E-mail: info\_ro@festo.com

**Russia**  
OOO Festo-RF  
Michurinskiy prosp., 49  
119607 Moscow  
Tel. +7 495 737 34 00, Fax +7 495 737 34 01  
E-mail: info\_ru@festo.com

**Singapore**  
Festo Pte. Ltd.  
6 Kian Teck Way  
Singapore 628754  
Tel. +65 62 64 01 52, Fax +65 62 61 10 26  
E-mail: info@sg.festo.com

**Slovakia**  
Festo spol. s r.o.  
Gavlovičová ul. 1  
83103 Bratislava 3  
Tel. +421 (0)2 49 10 49 10,  
Fax +421 (0)2 49 10 49 11  
E-mail: info\_sk@festo.com

## Festo worldwide

**Slovenia**  
Festo d.o.o. Ljubljana  
IC Trzin, Blatnica 8  
1236 Trzin  
Tel. +386 (0)1 530 21 00,  
Fax +386 (0)1 530 21 25  
E-mail: info\_sl@festo.com

**South Africa**  
Festo (Pty) Ltd.  
22-26 Electron Avenue  
P.O. Box 255  
Isando 1600  
Tel. +27 (0)11 971 55 00,  
Fax +27 (0)11 974 21 57  
E-mail: info\_za@festo.com

**Spain**  
Festo Pneumatic, S.A.U.  
Avenida Granvia, 159  
Distrito Económico Granvia L'H  
08908 Hospitalet de Llobregat  
Barcelona  
Tel. +34 901243660, Fax +34 902243660  
E-mail: info\_es@festo.com

**Sweden**  
Festo AB  
Stillmångsgatan 1  
Box 21038  
200 21 Malmö  
Tel. +46 (0)20 38 38 40, Fax +46 (0)40 38 38 10  
E-mail: order@festo.se

**Switzerland**  
Festo AG  
Moosmattstrasse 24  
8953 Dietikon ZH  
Tel. +41 (0)44 744 55 44,  
Fax +41 (0)44 744 55 00  
E-mail: info\_ch@festo.com

**Taiwan**  
Festo Co., Ltd.  
Head Office  
9, Kung 8th Road  
Linkou 2nd Industrial Zone  
Linkou Dist., New Taipei City  
24450 Taiwan, R.O.C.  
Tel. +886 (0)2 26 01-92 81,  
Fax +886 (0)2 26 01 92 86-7  
E-mail: festotw@tw.festo.com

**Thailand**  
Festo Ltd.  
Viranuvat Building, 6th - 7th Floor.  
1250 Bangna - Trad Road (Soi 34)  
Bangna, Bangkok 10260  
Tel. 1-800-290-477,+66 - 2785 -3700,  
Fax 1-800-290-478  
E-mail: info\_th@festo.com

**Turkey**  
Festo San. ve Tic. A.S.  
Istanbul Anadolu Yakasi Organize Sanayi Bolgesi  
Aydinli Mah. TEM Yan Yol Cad. No:16  
34953 Tuzla - Istanbul/TR  
Tel. +90 (0)216 585 00 85,  
Fax +90 (0)216 585 00 50  
E-mail: info\_tr@festo.com

**Ukraine**  
DP Festo  
ul. Borisoglebskaya,11  
04070, Kiev  
Tel. +380 (0)44 233 6451,  
Fax +380 (0)44 463 70 96  
E-mail: orders\_ua@festo.com

**United Kingdom**  
Festo Limited  
Applied Automation Centre  
Caswell Road  
Brackmills Trading Estate  
Northampton NN4 7PY  
Tel. +44 (0)1604 / 66 70 00,  
Fax +44 (0)1604 / 66 70 01  
E-mail: info\_gb@festo.com

**United States**  
Festo Didactic Inc.  
607 Industrial Way West  
Eatontown, NJ 07724  
Tel. +1 (732) 938-2000  
Fax +1 (732) 774-8573  
E-mail: services.didactic@festo.com

**Venezuela**  
Festo C.A.  
Av. 23 esquina con calle 71  
119607 Moscow  
Nº 22-62, Edif. Festo.  
Sector Paraiso  
Maracaibo - Venezuela  
Tel. +58 (261) 759 11 20/759 41 20/759 44 38,  
Fax +58 (261) 759 04 55  
E-mail: festo@festo.com.ve

**Vietnam**  
Festo Co Ltd  
(Cong ty TNHH FESTO)  
No. 1515 - 1516 Van Dai Dong Street  
Ward An Phu, District 2  
Ho Chi Minh City  
Tel. +84 (8) 62 81 44 53 - 4454,  
Fax +84 (8) 62 81 4442  
E-mail: info\_vn@festo.com

FESTO

Student Manual

Programmable Logic Controller

# Programmable Logic Controller

FESTO

Industrial Maintenance

LabVolt Series

Student Manual



Festo Didactic  
en  
39436-00

**Industrial Maintenance**

# **Programmable Logic Controller**

**Student Manual**

39436-00

Order no.: 39436-00

First Edition

Revision level: 09/2015

By the staff of Festo Didactic

© Festo Didactic Ltée/Ltd, Quebec, Canada 2007

Internet: [www.festo-didactic.com](http://www.festo-didactic.com)

e-mail: [did@de.festo.com](mailto:did@de.festo.com)

Printed in Canada

All rights reserved

ISBN 978-2-89640-128-4 (Printed version)

ISBN 978-2-89640-703-3 (CD-ROM)

Legal Deposit – Bibliothèque et Archives nationales du Québec, 2007

Legal Deposit – Library and Archives Canada, 2007

The purchaser shall receive a single right of use which is non-exclusive, non-time-limited and limited geographically to use at the purchaser's site/location as follows.

The purchaser shall be entitled to use the work to train his/her staff at the purchaser's site/location and shall also be entitled to use parts of the copyright material as the basis for the production of his/her own training documentation for the training of his/her staff at the purchaser's site/location with acknowledgement of source and to make copies for this purpose. In the case of schools/technical colleges, training centers, and universities, the right of use shall also include use by school and college students and trainees at the purchaser's site/location for teaching purposes.

The right of use shall in all cases exclude the right to publish the copyright material or to make this available for use on intranet, Internet and LMS platforms and databases such as Moodle, which allow access by a wide variety of users, including those outside of the purchaser's site/location.

Entitlement to other rights relating to reproductions, copies, adaptations, translations, microfilming and transfer to and storage and processing in electronic systems, no matter whether in whole or in part, shall require the prior consent of Festo Didactic.

















Information in this document is subject to change without notice and does not represent a commitment on the part of Festo Didactic. The Festo materials described in this document are furnished under a license agreement or a nondisclosure agreement.

Festo Didactic recognizes product names as trademarks or registered trademarks of their respective holders.

All other trademarks are the property of their respective owners. Other trademarks and trade names may be used in this document to refer to either the entity claiming the marks and names or their products. Festo Didactic disclaims any proprietary interest in trademarks and trade names other than its own.









# Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
	<b>DANGER</b> indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
	<b>WARNING</b> indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
	<b>CAUTION</b> indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
	<b>CAUTION</b> used without the <i>Caution, risk of danger</i> sign  , indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
	Direct current
	Alternating current
	Both direct and alternating current
	Three-phase alternating current
	Earth (ground) terminal



# Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to [did@de.festo.com](mailto:did@de.festo.com).

The authors and Festo Didactic look forward to your comments.

# Table of Contents

Preface .....	VII
About This Manual .....	IX
<b>Unit 1      Programmable Logic Controller.....</b>	<b>1</b>
<b>Ex. 1-1      PLC Overview.....</b>	<b>5</b>
<b>Ex. 1-2      Control Relay Functions .....</b>	<b>17</b>
<b>Ex. 1-3      Boolean Logic and Markers.....</b>	<b>27</b>
<b>Ex. 1-4      Timing Relay Functions .....</b>	<b>33</b>
<b>Ex. 1-5      Counter and Comparator Functions.....</b>	<b>43</b>
<b>Unit 2      PLC Control Circuits .....</b>	<b>53</b>
<b>Ex. 2-1      Interfacing Voltages .....</b>	<b>55</b>
<b>Ex. 2-2      Motor Starters with Jogging.....</b>	<b>65</b>
<b>Ex. 2-3      Reversing Motor Starters with Jogging .....</b>	<b>77</b>
<b>Appendix A   Equipment Utilization Chart .....</b>	<b>91</b>
<b>Appendix B   Diagram Symbols .....</b>	<b>93</b>
<b>Appendix C   PLC and Software Reference .....</b>	<b>97</b>
<b>Appendix D   Basic Setup and Lockout/Tagout ProceduresAnswers to                          Unit Test Questions.....</b>	<b>103</b>
<b>Appendix E   Boolean Algebra and Digital Logic.....</b>	<b>105</b>
<b>Bibliography .....</b>	<b>109</b>



# Preface

The Lab-Volt PLC Training System, model 8036-20, introduces the use of programmable logic controllers (PLCs) to control electric motors.

This training system is part of the Industrial Controls training program which provides a thorough understanding of the theory and operation of electric motor controllers.

We hope that your learning experience will be the first step of a successful career.



# About This Manual

The exercises in this manual, *Programmable Logic Controller*, complement the exercises contained in the manual *Basic Controls*. They provide the knowledge necessary to realize motor controls with the help of a PLC.

The present manual is divided into two units:

- Unit 1 introduces the PLC and its main functions;
- Unit 2 includes PLC circuits that are equivalent to those realized in the manual *Basic Controls*.

Each unit contains exercises which provide a systematic and realistic means of learning the subject matter. Each exercise is divided into the following sections:

- A clearly defined *Exercise Objective*;
- A *Discussion* of the theory involved in the exercise;
- A *Procedure Summary* which provides a bridge between the theoretical *Discussion* and the laboratory *Procedure*;
- A step-by-step laboratory *Procedure* in which the students observe and quantifies important principles covered in the *Discussion*;
- A *Conclusion* to summarize the material presented in the exercise;
- *Review Questions* to verify that the material has been well assimilated.

A ten-question test at the end of each unit allows the student's knowledge of the unit material to be assessed.



## Safety Considerations

Make sure that you are wearing appropriate protective equipment before performing any of the exercises in this manual. Remember that you should never perform an exercise if you have any reason to think that a manipulation could be dangerous to you or your teammates.

## Reference Material

Refer to the PLC's user manual from Moeller for detailed information on how to use the device.

## Prerequisite

To perform the exercises in this manual, you should have completed the manual *Basic Controls*, Lab-Volt part number 39163 (or 87774).

Before performing an exercise, you should have read the pages of the PLC's user manual that deal with the covered topics. Ask your instructor for a copy, or download the file from Moeller's web site.

# About This Manual

## **PLC programming**

There are two ways of programming the Moeller's EASY™ programmable logic controller supplied with the training system:

- By using the buttons located on the PLC. This is the method that will be shown throughout the exercises;
- With the help of the EASY-SOFT™ software. This method, requiring a PC running under a Microsoft Windows™ operating system, is explained in Appendix C.

# Programmable Logic Controller

## UNIT OBJECTIVE

Upon completion of this unit, you will be able to implement small control programs using the Lab-Volt Programmable Logic Controller module.

## DISCUSSION OF FUNDAMENTALS

As you have seen in the manual *Basic Controls*, motors can be controlled in a variety of ways. You have learned that they can be started, reversed, jogged, or stopped using individual controllers and relays. However, you can well imagine that employing a multitude of single-purpose devices can soon become time-consuming, with each apparatus requiring particular wiring.

Programmable Logic Controllers (PLCs) are small computers used for automation of industrial processes, such as control of machinery on factory assembly lines. Like personal computers, PLCs use a microprocessor. Some PLCs are built to sustain extended temperature ranges, dirty or dusty conditions, vibrations, and impacts.

The special input/output arrangements of PLCs is a major difference with computers. PLCs are connected to sensors (push buttons, limit switches, temperature indicators) and actuators (motor starters, magnetic relays or solenoids). The input/output arrangements may be built into a simple PLC, or the PLC may have external input/output modules.

Depending on its size, a single PLC can be programmed to replace a considerable number of control relays, timers and counters, hence saving a lot of hardwiring and troubleshooting time. Furthermore, PLCs offer more flexibility than conventional wiring. In effect, when a control process needs to be changed, the program can simply be modified, which is much easier than rewiring the entire process. This is another reason why PLCs are so often preferred in today's world of manufacturing.

## PLC hardware

The main components of PLC systems are:

- **Power supply:** Provides constant output voltage from the incoming system voltage. The Lab-Volt Industrial Control System includes a separate DC power supply. The DC Power Supply, Model 3139, shown in Figure 1-1, provides 24 V dc to the PLC and other DC components of the system.





Figure 1-1. DC Power Supply, Model 3139.

- **Input/output section:** Input ports receive data signals from external devices, including push buttons, limit switches, and electronic sensors. Output ports take the commands from the processor to activate/deactivate the devices connected to them. Input and output ports can be discrete or analog.
- **Processor section:** This is the "brain" of the PLC system, comprising the microprocessor and the memory. The processor reads the input data, executes the stored software program, and sends commands to output modules.
- **Programming section:** PLCs have at least one communication port used for programming, troubleshooting, sharing data, attaching a visual display, attaching a modem, or connecting to a network. PLCs are often connected to the plant's communication network. This enables the PLC to be part of a larger control system and to be remotely accessed.

## PLC software

PLCs may be programmed in different ways:

- **Dedicated buttons:** The program of some small PLCs can be entered with the help of dedicated buttons and a LCD screen located directly on the PLC.
- **Handheld terminal:** Portable programming unit that can be connected to the PLC. This rugged device has a display screen and buttons to permit programming. It can usually store backup copies of programs and communicate with computers.

- **Computer:** PLC manufacturers offer software that permits PLC programming. This is often the preferred method, because computers have large data storage capacity and a wider screen, which displays more information at the same time. Also, laptops offer the same portability as handheld devices, although they are more fragile.

Different programming languages exist for PLCs. Some are graphical (ladder logic, function block diagram, sequential function chart) while others are textual (structured text, instruction list). Figure 1-2 shows an example of the most popular language: the ladder logic. As the figure shows, this type of circuit resembles schematic diagrams and therefore, makes it easy for technicians to understand the circuit and trace the problems. In ladder logic, the "rails" represent the power lines and the "rungs" contain the items of the process sequence. This manual will concentrate on ladder logic.

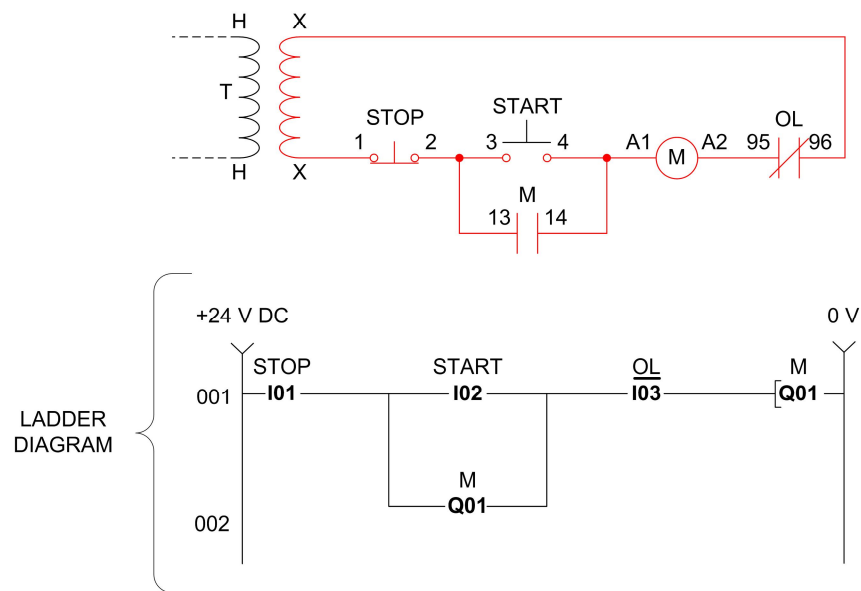


Figure 1-2. Schematic and ladder logic diagrams.



## PLC Overview

### EXERCISE OBJECTIVE

- Familiarize yourself with the Programmable Logic Controller module.
- Program and test a basic ladder logic circuit.

### DISCUSSION

A programmable logic controller is a solid-state device used for implementing logic functions previously performed by electromagnetic relays. Some of the instructions represent the internal and external output devices connected to the PLC. Other instructions are internal and are used to establish the conditions under which the PLC will energize or de-energize output devices, with relation to the status of the input devices.

The most popular programming format for PLCs is the ladder diagram, which uses a symbology similar to schematic diagrams of hardwired circuits. A major difference between hardwired and ladder circuits resides in the fact that a hardwired circuit's rung requires "electrical" continuity to energize a coil, whereas a PLC ladder rung requires "logical" continuity to actuate an output.

Figure 1-3 shows the Programmable Logic Controller module, Model 3128, which includes the EASY 512-DC-R PLC from Moeller. This PLC can be programmed directly on the device, via dedicated buttons, or by downloading a program created through the EASY-SOFT software. The eight input and four output terminals of the PLC can be accessed through banana jacks mounted on the module faceplate.



Figure 1-3. Programmable Logic Controller module, Model 3128.

### Input and output terminals

The PLC input terminals provide a means of connecting external input signals to the PLC. Each input terminal is numbered (from I1 to I8) to permit the use of its corresponding variable in the PLC programs. Examples of input devices are limit switches, flow switches, proximity switches, float switches, and thermal switches. The LCD screen shows, at the top of the status display, which input signals are actuated. In the status display shown in Figure 1-4, inputs I1 and I2 are actuated.



Figure 1-4. Programmable Logic Controller status display.

The PLC controls output devices via its output relays. The contacts of these output relays open and close depending on program instructions. Examples of output devices connected are lights, contactors, relays, motor starters for pumps, fans, etc. When a PLC output terminal is enabled (closed contact), the corresponding output number appears at the bottom of the status display. In the status display shown in Figure 1-4, output Q1 is actuated.

### Ladder program editing

Figure 1-5 shows a ladder program on the circuit diagram display of the PLC. As shown in this figure, the ladder programs of this PLC contain four columns. Three of them are contact fields and one is a coil field. Every program row corresponds to a rung and the lines linking the different elements are logical connections.

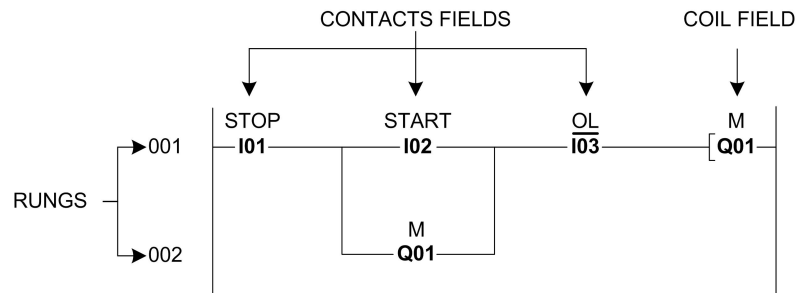


Figure 1-5. PLC ladder program.

The contacts and coils of the PLC program can be inputs and outputs connected to the PLC terminals, but they can also be located inside the PLC. Examples of such internal relays are comparators, counters, and markers.

The list of the supported contacts and coils of the EASY 512-DC-R PLC is presented in Table 1-1.

CONTACT DESCRIPTION	RANGE	COIL FUNCTION	PARAMETERS
Analog value comparator	A1 to A16	NO	YES
Counter function relay	C1 to C16	YES	YES
Text marker function relay <sup>(1)</sup>	D1 to D16	YES	YES
Input terminal	I1 to I8	NO	NO
Marker	M1 to M16	YES	NO
Marker	N1 to N16	YES	NO
Operating hours counter	O1 to O4	YES	YES
Cursor button <sup>(2)</sup>	P1 to P4	NO	NO
Output terminal	Q1 to Q4	YES	NO
Timing relay	T1 to T16	YES	YES
Jump label	:1 to :8	YES	NO
Master reset	Z1 to Z3	YES	NO
<sup>1</sup> Text marker function relays (D) can only be edited via the Easy-Soft programming software. <sup>2</sup> Cursor buttons (P) are not activated by default.			






**Table 1-1. Contacts and coils of the EASY 512-DC-R PLC.**

**Note:** Unsupported contacts such as the 7-day switch function relays (☺), expansion input (R), and output (S) terminals, or Year time switch (Y) can be programmed into the PLC but will always remain at logic 0.

The program coils are represented by three symbols. For example, the coil in Figure 1-5 is represented by  $\{Q01$ , where:

- $\{$  is the contactor coil function,
- Q means output terminal,
- 01 stands for the first coil of this kind (the 0 is omitted in the circuit diagram display of the PLC).

The switching behavior of a relay changes according to its coil function:

COIL FUNCTION	SYMBOL	DESCRIPTION
Contact		The make contact is set to logic 1 as long as the coil is actuated. <sup>(1)</sup>
Negated contact		The make contact is set to logic 1 as long as the coil is <b>NOT</b> actuated.
Set	<b>S</b>	The make contact is maintained to logic 1 once the set coil is actuated, even for a short period.
Reset	<b>R</b>	The make contact is maintained to logic 0 once the reset coil is actuated, even for a short period.
Falling edge pulse		The make contact is switched to logic 1 for the duration of one cycle with a change in coil state from 1 to 0.
Rising edge pulse		The make contact is switched to logic 1 for the duration of one cycle with a change in coil state from 0 to 1.
Impulse relay		The contacts switch every time the coil goes from state 0 to state 1.
<sup>1</sup> Make contacts close when the corresponding coil is energized, whereas break contacts open when the matching coil is actuated.		

**Table 1-2. Coil functions.**

**Note:** Using twice the same coil function (for instance two times SQ1) can lead to unpredictable results. However, you can use more than one coil function for the same coil (i.e., SQ1 and RQ1), or use the associated contact as often as necessary.

### PLC start-up procedure

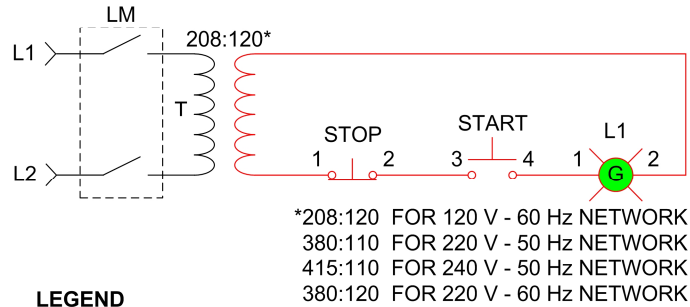
Upon start-up, the PLC may be in the RUN or STOP mode depending on whether or not it has a valid program, or how it has been set to start. If the PLC is set to start in the RUN mode and has a valid program, the program will start automatically when powered. This may lead to unwanted events, if the operator does not follow proper start-up procedures.

A general start-up procedure should be performed whenever a controller system is to be put into operation. The purpose of this procedure is to isolate problems such as wiring errors, input and output device malfunctions, and programming errors in a systematic, controlled manner. Following a start-up procedure is particularly important when working on automated electromechanical systems because the functions being performed by a programmed system may not be readily apparent to the operator.



## Procedure Summary

In this exercise, you will implement the simple push button circuit shown in Figure 1-6 using the Programmable Logic Controller module. In order to program the PLC, you will navigate through the different menus.



### LEGEND

- L1 = START PILOT LIGHT (GREEN)
- START = START PUSH BUTTON (MOMENTARY CONTACT)
- STOP = STOP PUSH BUTTON (MOMENTARY CONTACT)
- T = CONTROL VOLTAGE TRANSFORMER
- LM = LOCKOUT MODULE

Figure 1-6. Schematic diagram of the push button circuit.

You will then press the START and STOP push buttons to test if the PLC works the way it should.

In this circuit, the green pilot light turns on when the START push button is pressed, unless the STOP push button is pressed as well.

## EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

## PROCEDURE



The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

### Basic setup

- ☐ 1. Perform the Basic Setup procedure shown in section I of Appendix D.

### Programmable Logic Controller module connection

- ☐ 2. Connect the Programmable Logic Controller module as follows:
  - Connect the Control Transformer terminals H1 and H2 to terminals L1 and L2 of the Lockout Module.
  - Connect the DC Power Supply to terminals X1 and X2 of the Control Transformer.
  - Connect the Programmable Logic Controller module to the DC Power Supply, using mini banana jack leads and respecting polarity.

### PLC programming

- ☐ 3. Perform the Energizing procedure shown in Section III of Appendix D.
- ☐ 4. The LCD window of the PLC turns on and presents the state of the different inputs and outputs. Press the OK button to switch from the status display to the main menu shown in Figure 1-7.

**Note:** If the PLC is in the RUN mode, press the down arrow cursor and the OK button to switch to the STOP mode. The PLC may only be programmed while in the STOP mode.



Figure 1-7. PLC main menu.

- ☐ 5. Using the arrows, select the PROGRAM item and press the OK button.

In the next menu, select the DELETE PROG. item, then press the OK button twice to delete the existing program.

Select the PROGRAM item, then press the OK button to reach the circuit diagram display shown in Figure 1-8. The display is currently empty and a cursor flashes at the top left.



Figure 1-8. Circuit diagram display.

- ☐ 6. Enter the program shown in Figure 1-9.

**Note:** An overview of the PLC buttons and functions is given in Appendix C. Refer to the user manual of the PLC to obtain detailed instructions.

*Programming tips*

- To insert an element in the circuit, press OK and select the appropriate input/output item with the cursor buttons. Press OK again to confirm your choice.
- The direction buttons are also used to change position in the window.
- The ALT button permits the insertion of a line.
- The DEL button deletes unwanted elements.
- The first three columns are the contact (input) fields and the remaining column is the coil (output) field. The sign ( [ ) before Q1 indicates that the output behaves like a contactor.
- When all contact fields of a rung are not used, the last contact must be wired directly to the coil field. To wire the contact to the coil, press ALT to activate the arrow and press the cursor buttons to move it.

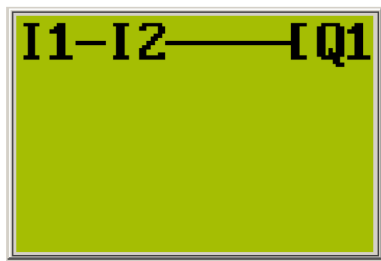


Figure 1-9. PLC ladder program.

- ☐ 7. Once the program is entered, press the ESC button.

Press OK to save the program, then set the PLC to the RUN mode.

- ☐ 8. Perform the Lockout/Tagout procedure shown in Section II of Appendix D.
- ☐ 9. Connect the PLC inputs and outputs according to the Figure 1-10 connection diagram. I1 is the START push button input, and I2 is the STOP push button input. The green pilot light is connected to output Q1.

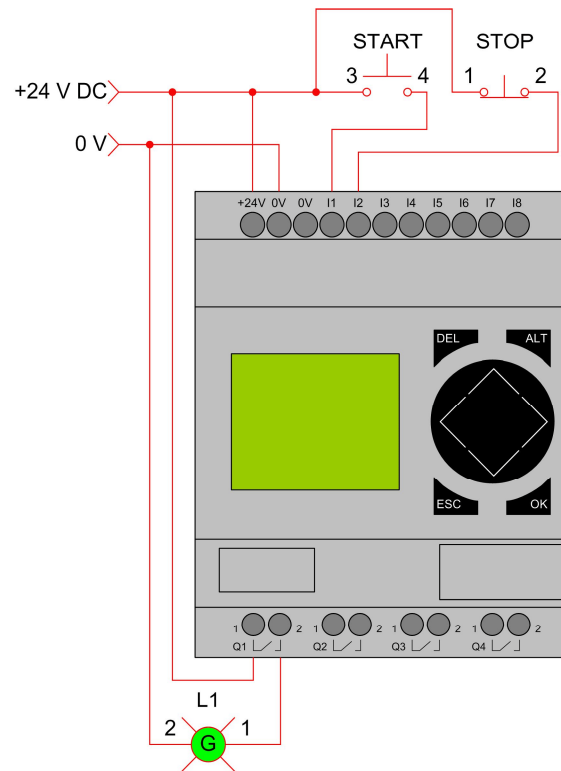
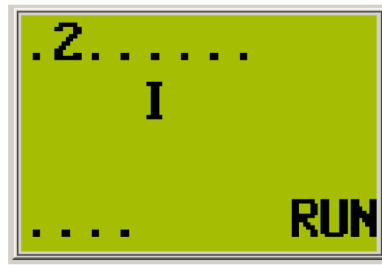


Figure 1-10. Circuit connection diagram.

- ☐ 10. Perform the Energizing procedure.

- ☐ 11. You should obtain the display shown in Figure 1-11.



**Figure 1-11. PLC's status display after the Energizing procedure.**

- ☐ 12. Press the different push button combinations. Indicate if a "1" appears at the bottom left of the LCD display, meaning that output Q1 is activated when:

- No button is pressed: ☐ Yes ☐ No
- Only the START push button is pressed: ☐ Yes ☐ No
- Only the STOP push button is pressed: ☐ Yes ☐ No
- Both push buttons are pressed simultaneously: ☐ Yes ☐ No

- ☐ 13. Does the green pilot light illuminate when:

- No button is pressed: ☐ Yes ☐ No
- Only the START push button is pressed: ☐ Yes ☐ No
- Only the STOP push button is pressed: ☐ Yes ☐ No
- Both push buttons are pressed simultaneously: ☐ Yes ☐ No

- ☐ 14. Does the pilot light illuminate following the "1" indicator at the bottom of the status display?

☐ Yes ☐ No

- ☐ 15. Set the PLC to the STOP mode.

Turn the individual power switch of the AC Power Supply off, disconnect the circuit, and return the equipment to the storage location.

## CONCLUSION

In this exercise, you familiarized yourself with the Programmable Logic Controller module. You learned how to enter a basic ladder program into the PLC and you verified that the output responded correctly to the input signals.

## REVIEW QUESTIONS

1. In what mode does the Programmable Logic Controller module start by default, if a valid program is entered?
  - a. DISPLAY
  - b. PROGRAM
  - c. RUN or STOP
  - d. PARAMETER
  
2. Which device can appropriately be connected to a PLC's "Q" terminal?
  - a. Push button
  - b. Limit switch
  - c. Pilot light
  - d. Power supply
  
3. Which device can appropriately be connected to a PLC's "I" terminal?
  - a. Pilot light
  - b. Limit switch
  - c. Motor starter
  - d. Power supply
  
4. What does a PLC rung require to energize an output?
  - a. Electrical continuity
  - b. Logical continuity
  - c. Break in continuity
  - d. None of the above is correct.

5. If you keep the connections shown in Figure 1-10, but change the program shown in Figure 1-9 for the following one (Figure 1-12):

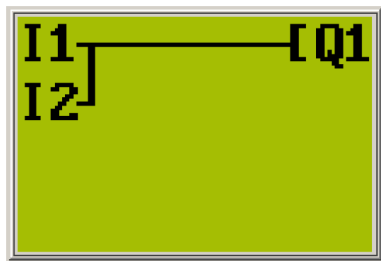


Figure 1-12. Question 5 PLC ladder program.

Under which circumstances would the pilot light **NOT** be illuminated?

- a. When both push buttons are pressed.
- b. When no push button is pressed.
- c. When only the start push button is pressed.
- d. When only the stop push button is pressed.

## Control Relay Functions

### EXERCISE OBJECTIVE

- Use a PLC for replacing the functions of a control relay.

### DISCUSSION

PLC circuits offer several advantages over conventional circuits using control relays:

- Less wiring;
- Configurability;
- Ease of expandability;
- Reduced space requirements;
- High reliability;
- Low power consumption.

Normally open (NO) and normally closed (NC) contacts in PLC programs are sometimes referred to as make and break contacts. Make contacts close when the corresponding coil is energized, whereas break contacts open when the corresponding coil is actuated. In PLC programs, break contacts are differentiated by a horizontal line located above the contact letter.

Often, normally open and normally closed switches are both represented by a make instruction in a PLC program. This apparent contradiction actually makes sense when considering that the ladder diagram must be evaluated in terms of logical continuity rather than electrical continuity. Thus, the normally open or normally closed mechanical action of a switch is not a consideration when programming a ladder instruction for this switch.

The amount of time the PLC takes to read all inputs, execute the program, and update all outputs, is called scan time. The Programmable Logic Controller module circuit diagrams, for instance, are processed cyclically every 2 to 40 ms, depending on their complexity.

When editing ladders, it is a good practice to minimize the number of programming steps, since PLCs have limited memory space to store program instructions. For example, the Programmable Logic Controller module may contain a maximum of 128 lines of logic, each line having 3 contact fields and 1 coil field.



### Latching (holding) circuits

Latching circuits allow to keep an output energized, even if the input is not kept actuated. A good example of this is a start push button, with a latching (holding) circuit in parallel, used to activate a motor. When an operator presses and releases the START push button, the motor keeps running until the STOP push button is pressed, because the latching contact stays closed. Traditionally, latching circuits are implemented using a control relay or a contactor NO contact.

Figure 1-13 shows a hardwired latching circuit controlling red and green pilot lights. When the START push button is pressed, the control relay contact closes, keeping the green pilot light on as long as the STOP push button is not pressed.

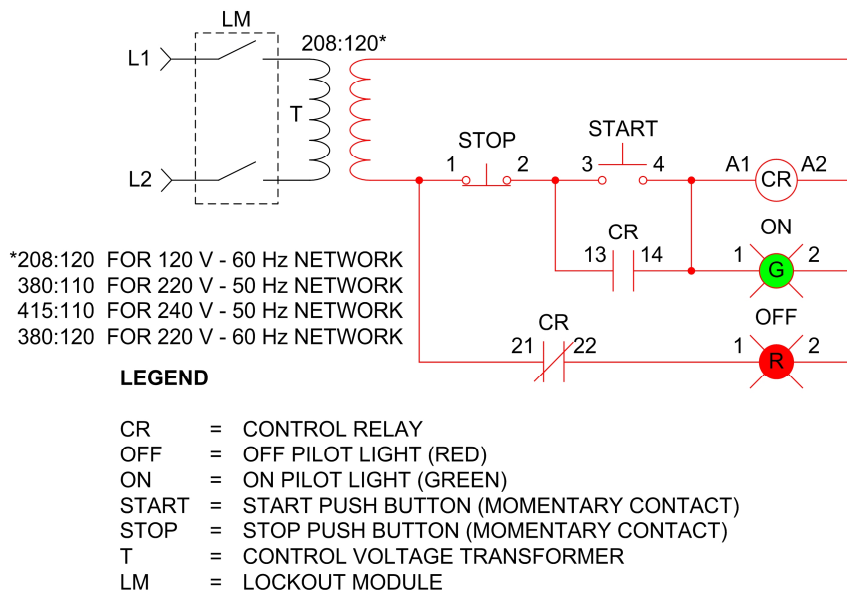


Figure 1-13. Latching circuit with a control relay.

This last circuit can be translated into an equivalent ladder program, as Figure 1-14 shows. When input I1 (START) is energized, the Q1 contactor output (green pilot light) switches to logic 1 and the green pilot light illuminates. The Q1 output then keeps itself actuated through its corresponding make contact. When input I2 (STOP) is pressed, the rung de-energizes. The red pilot light (Q2) illuminates when the green pilot light (Q1) does not.

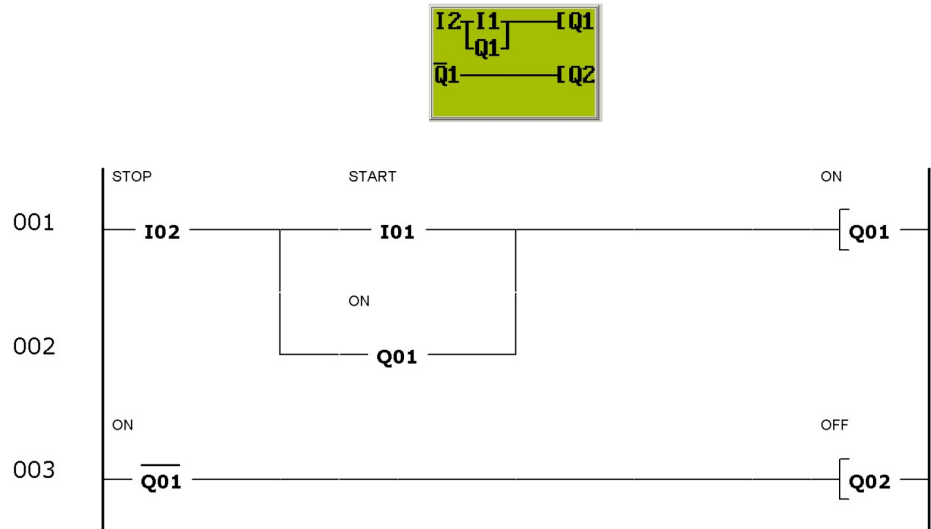


Figure 1-14. Latching circuit ladder program and equivalent circuit diagram display.

Another way of implementing this latching circuit is with the help of the set and reset instructions, as represented in Figure 1-15. When input I1 (START) is energized, output Q1 (green pilot light) is set to logic 1. To reset the Q1 coil, the STOP push button connected to I2 must be pressed. The I2 break contact is used because the STOP push button is a NC contact.

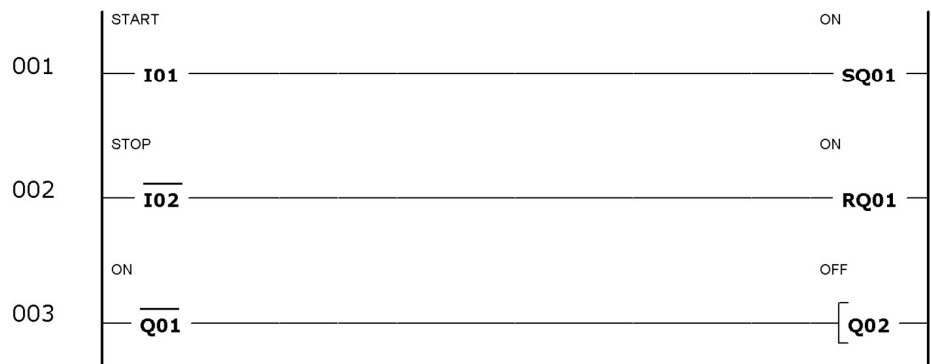


Figure 1-15. Latching circuit using the set and reset instructions ladder program.

### Power flow display

While troubleshooting a PLC circuit, it is often desirable to know which parts of the circuit are energized. Although it is possible to physically inspect all inputs and outputs of the PLC, it is often more convenient to observe the operation of the circuit graphically. The Programmable Logic Controller module enables visualization of which logical line is powered during PLC operation. This is done by accessing the circuit diagram display once in the RUN mode. The thick (or double) lines on the circuit represent logic 1 (powered) links, and thin lines represent connections of logic 0 (unpowered). In the power flow display of Figure 1-16, only the line connecting the break contact Q1 and the coil Q2 is energized.

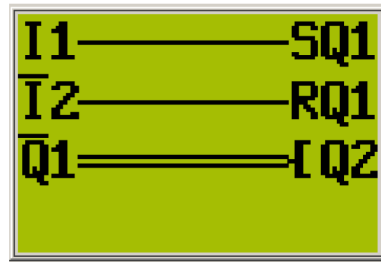


Figure 1-16. Power flow display.

### Procedure Summary

In the first part of this exercise, you will connect and test a circuit employing a hardwired relay to control two pilot lamps.

In the second part of the exercise, you will substitute the relay of the preceding circuit for a PLC and verify that this programmed circuit may function in a way equivalent to a hardwired circuit. To do so, you will program and test two different ladder programs.

Finally, you will observe the behavior of the program rungs during PLC operation with the help of the power flow display screen.

### EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

## PROCEDURE



The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

### Basic setup

- ☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

### Latching circuit using a control relay

- ☐ 2. Figure 1-13 shows the schematic diagram of a basic latching circuit with a control relay.

Set up the circuit. Make sure that you are using the Pilot Lights, model 3115, and Push Buttons, model 3110 (AC modules).

- ☐ 3. Perform the Energizing procedure.
- ☐ 4. Does latching occur when you press the START push button?
  - ☐ Yes      ☐ No
- ☐ 5. Does pressing the STOP push button stop the latching?
  - ☐ Yes      ☐ No
- ☐ 6. Perform the Lockout/Tagout procedure, disconnect the circuit and remove the Pilot Lights, Push Buttons, and Control Relay modules.

### Latching circuit in PLC program

- ☐ 7. Connect the Programmable Logic Controller module as described in Exercise 1-1.
- ☐ 8. Perform the Energizing procedure.

- 9. Enter the program shown in Figure 1-14.

*Programming tip*

*Perform the following steps to program a break contact:*

- Position the cursor on the desired contact.
- Press OK and ALT once to obtain a line above the contact letter.
- Then, press OK twice to confirm the change. The presence of a line above the contact letter indicates a break contact.

- 10. Once the program is entered, press the ESC and OK buttons to save the program.

Perform the Lockout/Tagout procedure.

- 11. Connect the PLC inputs and outputs according to Figure 1-17. Make sure that you are using the Switches, model 3112, and Pilot Lights, model 3115-A (DC modules).

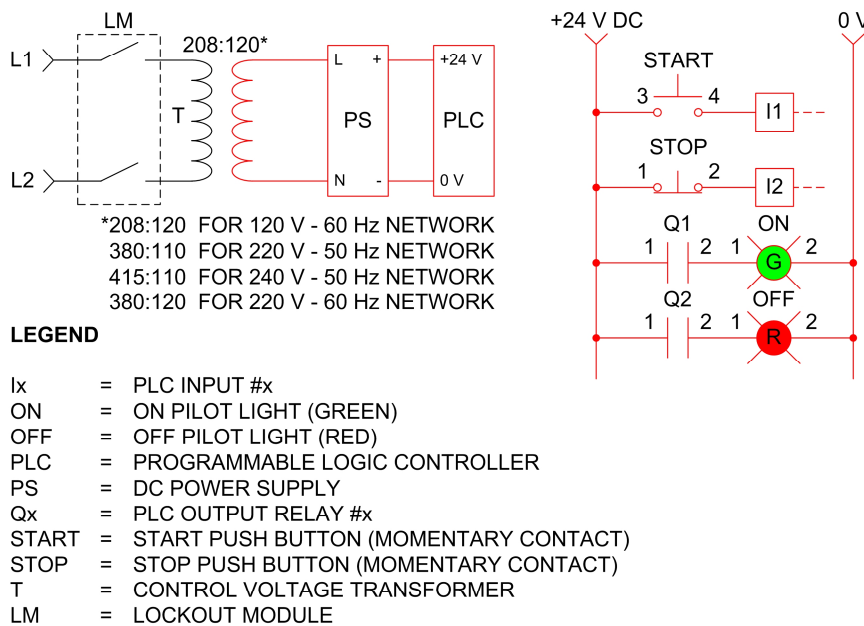


Figure 1-17. PLC input and output connections.

- 12. Perform the Energizing procedure.

**Note:** Make sure that the PLC is set to the RUN mode.

- ☐ 13. Check the pilot lights and the output numbers on the status display. Does latching occur when you press the START push button?

☐ Yes      ☐ No

- ☐ 14. Does pressing the STOP push button stop the latching?

☐ Yes      ☐ No

- ☐ 15. Are this program and the hardwired circuit equivalent in terms of functionality?

☐ Yes      ☐ No

- ☐ 16. Set the Programmable Logic Controller module to the STOP mode.

#### **Set and reset latching circuit**

- ☐ 17. Delete the existing program, then enter and save the program shown in Figure 1-15.

- ☐ 18. Set the Programmable Logic Controller module to the RUN mode.

Check the pilot lights and output numbers on the status display. Does latching occur when you press the START push button?

☐ Yes      ☐ No

- ☐ 19. Does pressing the STOP push button stop the latching?

☐ Yes      ☐ No

- ☐ 20. Are this program and the preceding one equivalent in terms of functionality?

☐ Yes      ☐ No

#### **Power flow display**

- ☐ 21. While the program is still running, access the main menu and press OK on the PROGRAM item to check the power flow display.

**Note:** *It is not possible to modify the program while in the RUN mode. However, as you will see later in this manual, some parameter values may be changed for testing purposes.*

Press the START push button. Which rung(s) is(are) powered while the push button is pressed?

- ☐ Rung 1    ☐ Rung 2    ☐ Rung 3

- ☐ 22. Press the STOP push button. Which rung(s) is(are) powered while the push button is pressed?

- ☐ Rung 1    ☐ Rung 2    ☐ Rung 3

- ☐ 23. Set the PLC to the STOP mode.

Turn the individual power switch of the AC Power Supply off, disconnect the circuit, and return the equipment to the storage location.

## CONCLUSION

In hardwired control relay diagrams, reference is made to actual control relay coils and contacts.

In PLC ladder programs, control relays are simulated, with NO or NC contacts becoming make or break instructions. Because of the limited PLC memory space, it is recommended that the number of rungs be reduced as much as possible.

In this exercise, you realized two PLC programs and found out that they were both performing the same functions as a hardwired control relay circuit. After that, you examined the power flow display to see which PLC program lines were energized.

## REVIEW QUESTIONS

1. Which advantage do PLCs have over control relays?
  - a. Reduced-space requirements
  - b. Ease of expandability
  - c. Higher reliability
  - d. All of the above are correct.
  
2. To what can we compare the make instruction?
  - a. Set instruction
  - b. NO contacts
  - c. NC contacts
  - d. Parallel rung

3. Why should the number of PLC program rungs be minimized?
  - a. To increase the number of contacts in the program.
  - b. To increase processor scan time.
  - c. The PLC memory size is limited.
  - d. None of the above is correct.
  
4. Which PLC instruction is used to make an output retain logic 1 value?
  - a. Reset
  - b. Set
  - c. Contactor
  - d. Negated contactor
  
5. Which display of the Programmable Logic Controller module shows which program rung parts are powered?
  - a. Power flow display
  - b. Main menu
  - c. Status display
  - d. Parameter display





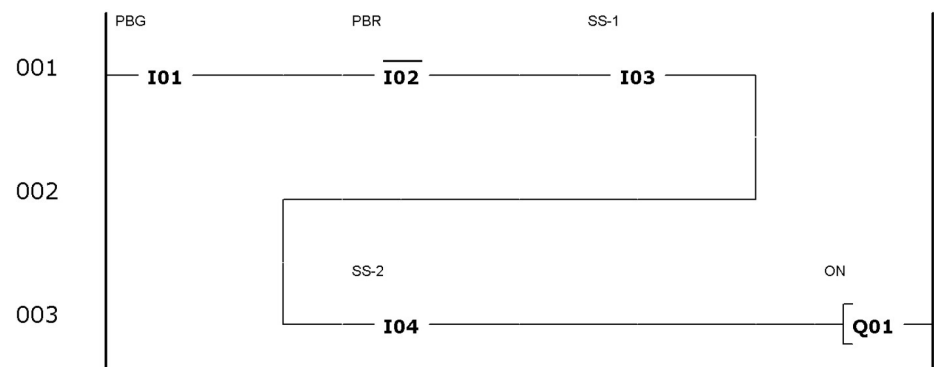
## Boolean Logic and Markers

### EXERCISE OBJECTIVE

- Use Boolean logic and markers to solve implementation problems.

### DISCUSSION

Because PLCs are limited in memory size, it is often necessary to circumvent those limitations by using some logic equivalents. The Programmable Logic Controller module, for instance, enables only three contacts per rung and does not permit backward wiring, which causes improper results. Figure 1-18 represents a series of four ANDed input contacts that is not implemented correctly.



**Figure 1-18. Do not use backwards wiring.**

The first method of solving the problem is to use markers to cut a long ANDed series of contacts. The Programmable Logic Controller module uses "M" and "N" markers to store values. Figure 1-19 shows how the preceding example may be implemented correctly with a marker.

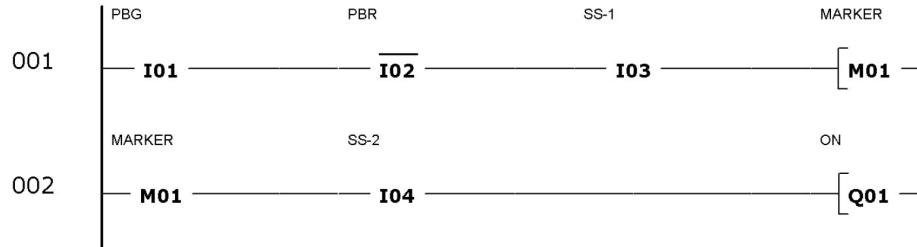


Figure 1-19. Using markers to avoid backwards wiring.

A second method of implementing the same circuit function is to use the principles of Boolean algebra reviewed in Appendix E. Knowing that a series of ANDed contacts is equivalent to ORed inverted contacts on a negated coil, we obtain the result in Figure 1-20. Note that make contacts are now break contacts and the break contact has become a make contact. The contactor coil is now a negated contactor coil (the coil contactor sign is inverted). This method, however, requires a greater number of rungs.

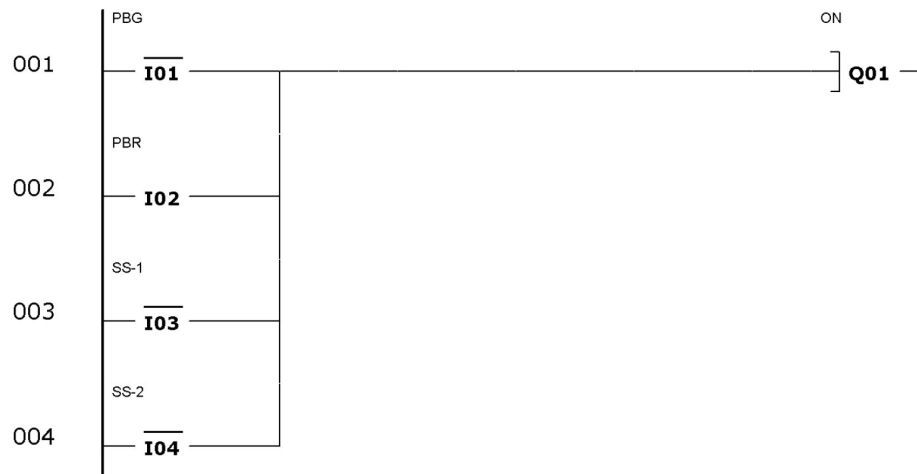


Figure 1-20. Boolean logic equivalent.

### Procedure Summary

The Programmable Logic Controller module enables only three contacts and one output per rung. In this exercise, you will have to implement a series of four contacts. To solve the problem, you will write three different ladder programs:

- Division of a series of contacts into two rungs using a marker;
- Application of boolean logic principles;
- Backwards wiring.

You will find out that the first two solutions give acceptable results, while the last one is impractical.

## EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

## PROCEDURE



The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

### Basic setup

- ☐ 1. Perform the Basic Setup procedure.

### Division of a series of contacts into two rungs using a marker

- ☐ 2. Connect the Programmable Logic Controller module as described in Exercise 1-1.

Perform the Energizing procedure.

Enter and save the program shown in Figure 1-19.

Perform the Lockout/Tagout procedure.

- ☐ 3. Connect the PLC inputs and outputs according to Figure 1-21.

**Note:** You will need two Switches modules. Use PBR, PBG, and L on the first module, and R on the second module.

- ☐ 4. Set the selector switch of the Switches modules to the O position.

Perform the Energizing procedure.

**Note:** Make sure that the PLC is set to the RUN mode.

- ☐ 5. According to the numbers you see on top of the status display, which switch(es) is(are) NC?

☐ I1      ☐ I2      ☐ I3      ☐ I4

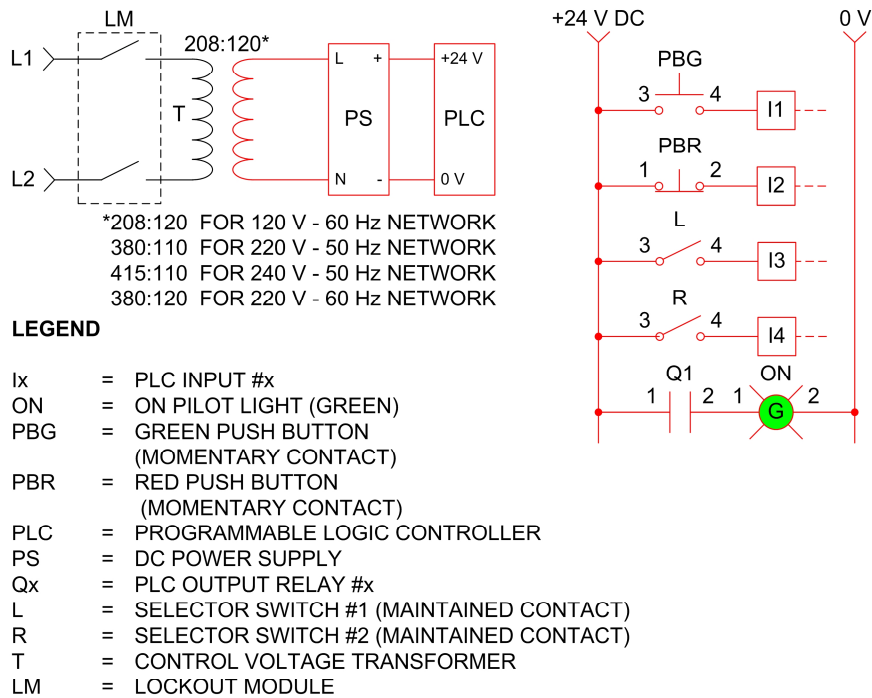


Figure 1-21. PLC input and output connections.

- ☐ 6. Access the PROGRAM menu to observe the power flow display as you modify the state of the different inputs.

Which input(s) do you have to activate to energize marker M1?

☐ I1    ☐ I2    ☐ I3    ☐ I4

- ☐ 7. Which input(s) do you have to activate to energize output Q1?

☐ I1    ☐ I2    ☐ I3    ☐ I4

### Application of Boolean logic principles

- ☐ 8. Set the Programmable Logic Controller module to the STOP mode.

Enter and save the program shown in Figure 1-20. The input/output connections remain the same.

Set the Programmable Logic Controller module to the RUN mode.

- ☐ 9. Which input(s) do you have to activate to energize output Q1?
- ☐ I1      ☐ I2      ☐ I3      ☐ I4
- ☐ 10. Do the circuits shown in Figures 1-19 and 1-20 behave similarly, in terms of what it takes to energize output Q1?
- ☐ Yes      ☐ No

### **Backward wiring**

- ☐ 11. Set the Programmable Logic Controller module to the STOP mode.
- Enter and save the program shown in Figure 1-18.
- Set the Programmable Logic Controller module to the RUN mode.
- ☐ 12. Are you able to energize the output contactor Q1?
- ☐ Yes      ☐ No
- ☐ 13. Is backward wiring supported by the PLC program?
- ☐ Yes      ☐ No
- ☐ 14. Set the PLC to the STOP mode.
- Turn the individual power switch of the AC Power Supply off, disconnect the circuit, and return the equipment to the storage location.

### **CONCLUSION**

In this exercise, you programmed three ladder diagrams that were meant to implement a long series of ANDed contacts. While backward wiring was not supported by the program, the use of a marker and an equivalent Boolean logic circuit turned out to be good practices to circumvent the problem.

### REVIEW QUESTIONS

1. What is the minimum number of program lines that you will need if you are implementing a circuit made of six inputs placed in series in the Programmable Logic Controller module?
  - a. 1
  - b. 2
  - c. 3
  - d. 4
  
2. What is the name of the PLC's auxiliary relays used to store values for later use?
  - a. Relays
  - b. Marker relays
  - c. Output relays
  - d. None of the above is correct.
  
3. What are contacts placed in series called?
  - a. ANDed contacts;
  - b. ORed contacts;
  - c. NOTed contacts;
  - d. NANDed contacts.
  
4. Which programming technique does the PLC not support?
  - a. Using a marker
  - b. Using equivalent boolean logic circuit
  - c. Using backwards wiring
  - d. All of the above are correct.
  
5. In Figure 1-19, if marker M1 is changed for marker N4 at the end of rung 1, which contact must start rung 2 to make the circuit work in the same manner?
  - a. M1
  - b. N1
  - c. M4
  - d. N4

## Timing Relay Functions

### EXERCISE OBJECTIVE

- Review PLC timing relay functions.

### DISCUSSION

Besides replacing electromechanical control relays, PLCs are also able to replace timing relays. While hardwired time-delay circuits are limited by the number of contacts or cams of their relays, PLC timing circuits are only limited by the memory space of the PLC.

Timing relay circuits are used in industrial control systems when an action is required after a specific delay time. They are used, for example, to postpone the startup of a motor, solenoid, or other electrically-driven device. They are also used to produce a delay before an electrically-driven device is de-energized.

The Programmable Logic Controller module includes 16 integrated timers that have the following coil functions:

- **On-delay (X):** As long as the rung conditions are true, the timer's accumulated value is incremented until it reaches a preset time value (I1). At that moment, the timer coil is triggered and the make contact is closed. The timer is reset when the rung conditions become false.
- **Random on-delay (?X):** Same as the on-delay function, except that the time needed to trigger the coil is randomly chosen within the setpoint value range (I1). For instance, if the setpoint is 10 seconds, the triggering time will be somewhere between 0 and 10 s.
- **Off-delay (■):** The timer coil is triggered and the make contact is closed when rung conditions are true. As soon as the rung conditions become false, the timer's accumulated value is incremented until it reaches a preset value (I1). After that delay, the timer coil de-energizes and the make contact opens. The timer accumulated value is reset when the rung conditions become true again.
- **Random off-delay (?■):** Same as the off-delay function, except that the time to de-energize the timer coil is randomly chosen within the setpoint value (I1) range.
- **On and off delay (X■):** Time delays are applied both for energizing and de-energizing the timing relay coil. For that reason, two different time values must be entered. The first one (I1) is for the on-delay and the second one (I2) is for the off-delay.



- **Random on and off delay (?X■):** Same as the on and off delay, except that the two delays are randomly chosen within the setpoint values (I1 and I2) range.
- **Single pulse switching (■):** Every time the rung conditions are true, the timer coil is triggered for the set time (I1) duration.
- **Flash switching (■):** Every time the rung condition is true, the timer coil switches alternately on and off. The first time value entered (I1) is the pulse duration. The second value (I2) is the pause time.

Each PLC timer has three different coils:

- **Trigger (T) coil:** Starts the timer when a rung becomes true (logic 1).
- **Stop (H) coil:** Halts the corresponding timer accumulator as long as it is enabled.
- **Reset (R) coil:** Resets the timing relay coil and contacts.

The time value in the Programmable Logic Controller module can be set according to different time bases, which have the following range:

- **Seconds (S):** From 0.000 to 99.999 s.
- **Minutes (M:S):** From 00:00 to 99:59.
- **Hours (H:M):** From 00:00 to 99:59.

### Procedure Summary

In this exercise, you will program a ladder circuit that uses the on and off delay function to control the turning on and turning off of two pilot lights. This program will resemble the hardwired circuit in Figure 1-22.

You will verify that the ladder program operates properly when the PLC's inputs and outputs are connected to switches and pilot lights.

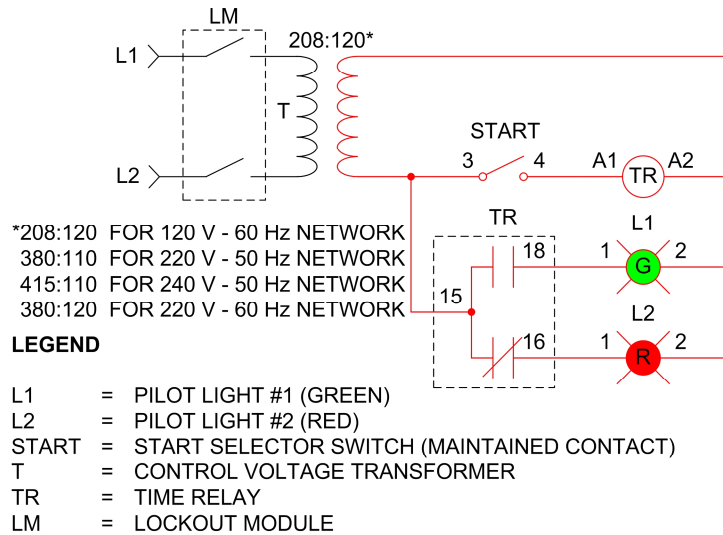


Figure 1-22. Hardwired timing relay circuit.

## EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

## PROCEDURE



The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

### Basic setup

- ☐ 1. Perform the Basic Setup procedure.

### Familiarization with the on and off delay function

- ☐ 2. Connect the Programmable Logic Controller module as described in Exercise 1-1.

Perform the Energizing procedure.

Enter and save the program shown in Figure 1-23, with the following timing relay (T1) parameter values:

- Coil function: trigger
- Mode: on and off delay
- Setpoint I1: 5 s
- Setpoint I2: 2 s

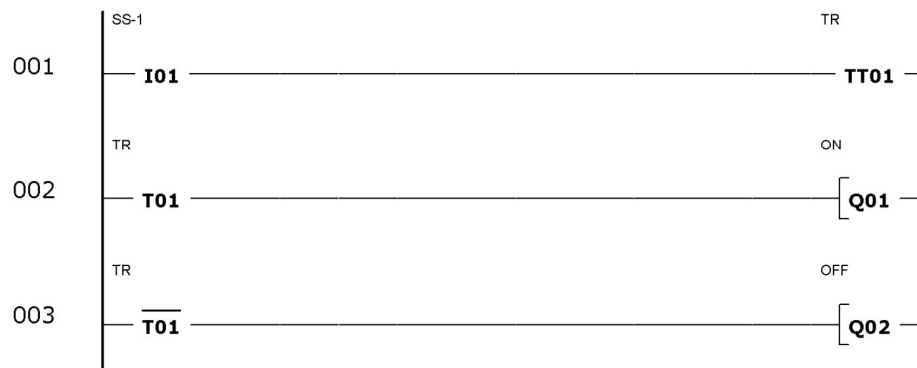


Figure 1-23. PLC timing relay ladder program.

Perform the Lockout/Tagout procedure.

- ☐ 3. Connect the PLC inputs and outputs according to Figure 1-24.

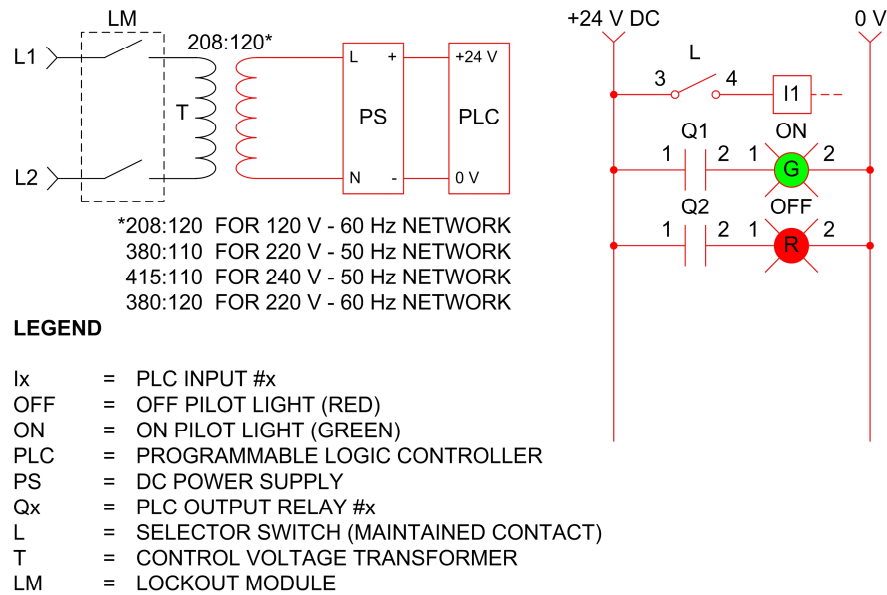


Figure 1-24. Connection diagram of the PLC timing relay circuit.

- ☐ 4. Set the selector switch of the Switches module to the O position.

Perform the Energizing procedure.

**Note:** Make sure that the PLC is set to the RUN mode.

- ☐ 5. According to the numbers you see on the status display, which input and/or output(s) are activated?

☐ I1    ☐ Q1    ☐ Q2

- ☐ 6. To what physical device(s) do these inputs and outputs correspond?

---



---

- ☐ 7. Access the circuit diagram display of the PLC. According to the power flow display, which rung(s) is(are) totally energized?

☐ Rung 1    ☐ Rung 2    ☐ Rung 3

- ☐ 8. Set the selector switch of the Switches module to the L position.

According to the power flow display, which rung(s) is(are) totally energized after 5 s?

☐ Rung 1   ☐ Rung 2   ☐ Rung 3

- ☐ 9. Set the selector switch of the Switches module to the O position. Does the green pilot light turn off?

☐ Yes, immediately  
☐ Yes, after a time delay of 2 s  
☐ No

- ☐ 10. According to the power flow display, which rung(s) is(are) now totally energized?

☐ Rung 1   ☐ Rung 2   ☐ Rung 3

- ☐ 11. Why cannot the red and green pilot lights be on at the same time?

---

---

- ☐ 12. Set the selector switch of the Switches module to the L position. Does the green pilot light turn on?

☐ Yes, immediately  
☐ Yes, after a time delay of 5 s  
☐ No

- ☐ 13. Access the circuit diagram display, then place the cursor on the TT1 item.

Press OK to access the timer 1 parameter display. Give a brief description of the following items shown on this display (refer to the PLC's user manual if necessary):

T1: \_\_\_\_\_

X■: \_\_\_\_\_

S: \_\_\_\_\_

+: \_\_\_\_\_

I1: \_\_\_\_\_

I2: \_\_\_\_\_

■: \_\_\_\_\_

T: \_\_\_\_\_

#### **Familiarization with the operation of the reset and stop coils**

- ☐ 14. Set the Programmable Logic Controller module to the STOP mode.

Modify your PLC program to include a reset coil (RT1) and a stop coil (HT1) as shown in the ladder program of Figure 1-25.

Perform the following steps:

- Use push button PBR to control the stop coil (connect to input I2) and PBG to control the reset coil (connect to input I3).
- Change the time setpoint 1 (I1) to 10 s.
- Set the selector switch of the Switches module to the O position.

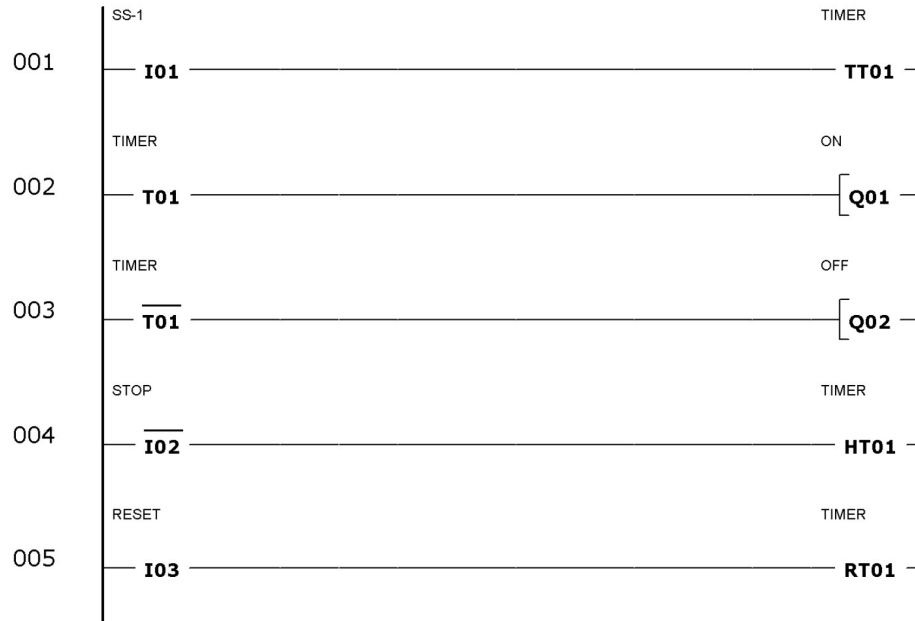


Figure 1-25. Ladder program of the PLC timing relay circuit.

- ☐ 15. Set the Programmable Logic Controller module to the RUN mode.
- ☐ 16. Access the circuit diagram display, then place the cursor on TT1. Press OK to access the timer 1 parameter display.

Set the selector switch of the Switches module to the L position while observing the timer's actual value at the bottom of the display.

How long does it take before the green pilot light turns on (when the timer's actual value stops)?

- 
- ☐ 17. Does that correspond to the on delay preset value?
    - ☐ Yes      ☐ No
  - ☐ 18. Set the selector switch of the Switches module to the O position, the green pilot light will turn off after 2 s.
  - ☐ 19. Familiarize yourself with the operation of the stop coil and reset coil by stopping and resetting the timer value during the on delay timing (before the timer attains 10 s).

- ☐ 20. Set the PLC to the STOP mode.

Turn the individual power switch of the AC Power Supply off, disconnect the circuit, and return the equipment to the storage location.

### CONCLUSION

In this exercise, you entered a PLC program resembling a hardwired timing relay circuit. You used the PLC on and off delay instruction to produce delays of 5 (on) seconds and 2 (off) seconds.

You connected switches and lights like in the hardwired circuit. However, the control and timing relays of the hardwired circuit were substituted for the Programmable Logic Controller module. You verified that the PLC on and off delay circuit worked just like the corresponding hardwired version by manipulating the different controls.

Finally, you familiarized yourself with the operation of the stop coil and reset coil.

### REVIEW QUESTIONS

1. What can a timing relay circuit be used for, in industrial controls?
  - a. Delay the startup of a motor.
  - b. Delay the deactivation of an electrically-driven device.
  - c. Make a pilot light flash.
  - d. All of the above are correct.
2. In Figure 1-25 program, which contact replaces the control relay (NO) holding contact of the hardwired circuit?
  - a. TT1
  - b. T1
  - c. I1
  - d. None of the above is correct.
3. In the Figure 1-25 program, which contact replaces the timing relay (NO) contact of the hardwired circuit?
  - a. M1
  - b. T1
  - c. I1
  - d. Q1



4. In the Figure 1-25 program, why cannot both pilot lights be on at the same time?
  - a. The timing relay controls Q1 coil.
  - b. Q2 output rung becomes true when Q1 output is actuated.
  - c. Q2 output rung becomes true when Q1 output is not actuated.
  - d. None of the above is correct.
  
5. How many setpoints are necessary in the on and off delay function of the Programmable Logic Controller module?
  - a. 1
  - b. 2
  - c. 3
  - d. 4

## Counter and Comparator Functions

### EXERCISE OBJECTIVE

- Review PLC counter and comparator functions.

### DISCUSSION

#### Counters

Programmable counters can perform the same functions as mechanical counters. They can count up, down, or both up and down. Counters are used when parts of a system must be activated and/or deactivated after a definite number of events has occurred.

The Programmable Logic Controller module includes 16 integrated counters that have the following coil functions:

- **Counter input (C):** Each time the counter rung makes a false-to-true transition, the actual value is incremented or decremented by one count.
- **Counting direction (D):** Counting up when the coil is not triggered, counting down when the coil is triggered.
- **Counter reset (R):** Actual value resets to 00000 when the coil is triggered.

The counter preset value specifies the value (setpoint) that the counter must reach before the counter's make contact actuates.

The counters of the Programmable Logic Controller module count between 0 and 32 000. If they reach one of these limits, the value is retained until the count direction is changed.

#### Analog Value Comparators

PLC comparator instructions can be used in conjunction with timer and/or counter instructions to control sequential processes. The time and counter actual values are compared between them, or with preset values. The comparator outputs "true" or "false" logic, depending upon whether or not the condition is met.

The comparator instructions of the Programmable Logic Controller module are listed below. Each instruction compares a pair of numerical values (I1 and I2).

- **Less than (LT):** True when I1 is less than I2.
- **Less than/equal to (LE):** True when I1 is less than or equal to I2.

- **Equal to (EQ):** True when I1 is equal to I2.
- **Greater than (GT):** True when I1 is greater than I2.
- **Greater than/equal to (GE):** True when I1 is greater than or equal to I2.

**Note:** The Not equal (NE) instruction is obtained by changing the make contact of an EQ comparator for a break contact.

When entering a comparison instruction, the sources of the two values to be compared (I1 and I2) must be specified. They can be constants, actual values of counter or timing relays, or analog input signals (usually from sensors). The Programmable Logic Controller module provides two (0-10 V) analog inputs, namely I7 and I8.

The I1 and I2 compared values can be modified by the following parameters:

- **Gain factors (F1 and F2):** F1 is the gain factor for I1 ( $I1 = F1 \times \text{actual I1 value}$ ). F2 is the gain factor for I2.
- **Offset (OS):** Offset for the value of I1 ( $I1 = OS + \text{actual value of I1}$ ).
- **Hysteresis (HY):** Switching hysteresis for I2. This value applies both to positive and negative hysteresis.

### Procedure Summary

In this exercise, you will program a ladder circuit employing counter and comparator functions.

The circuit will be activated by a selector switch. Upon starting, the timer T1 will be triggered. Every time the COUNT push button is pressed, the counter's actual value increases.

At the count of five, the green pilot light will turn on. At the count of ten, the comparator will cause the red pilot light to start flashing alternately, due to a timer function. The counter can be reset by pressing the RESET push button.

### EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

## PROCEDURE



The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

### Basic setup

- ☐ 1. Perform the Basic Setup procedure.

### Familiarization with the counter and comparator functions

- ☐ 2. Connect the Programmable Logic Controller module as described in Exercise 1-1.

Perform the Energizing procedure.

Enter and save the program shown in Figure 1-26, with the following parameter values:

#### Timer relay (T1)

- Coil function: trigger
- Mode: flash switching
- Setpoint I1: 0.5 s
- Setpoint I2: 0.5 s

#### Counter relay (C1)

- Coil function: count pulse
- Operand: constant
- Setpoint: 5

#### Comparator (A1)

- Comparator function: GE (greater than/equal to)
- Comparison value 1: counter C1
- Comparison value 2: 10

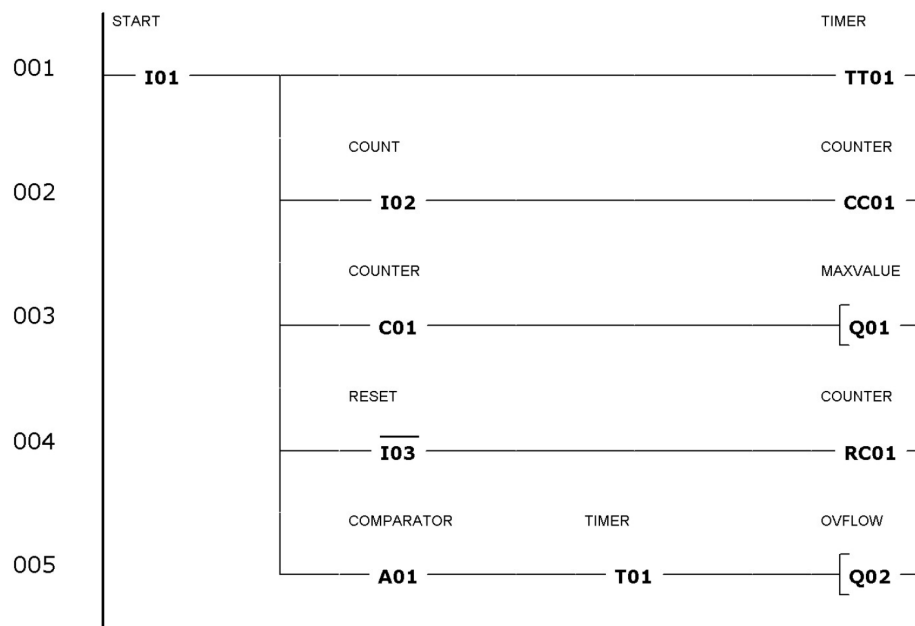


Figure 1-26. PLC counter and comparator circuit.

- ☐ 3. Access the circuit diagram display, then place the cursor on C1.

Press OK to access the counter 1 parameter display. Give a brief description of the following items shown on this display:

C1: \_\_\_\_\_

N: \_\_\_\_\_

+: \_\_\_\_\_

S: \_\_\_\_\_

C: \_\_\_\_\_

- ☐ 4. Perform the Lockout/Tagout procedure.
- ☐ 5. Connect the PLC inputs and outputs according to Figure 1-27.

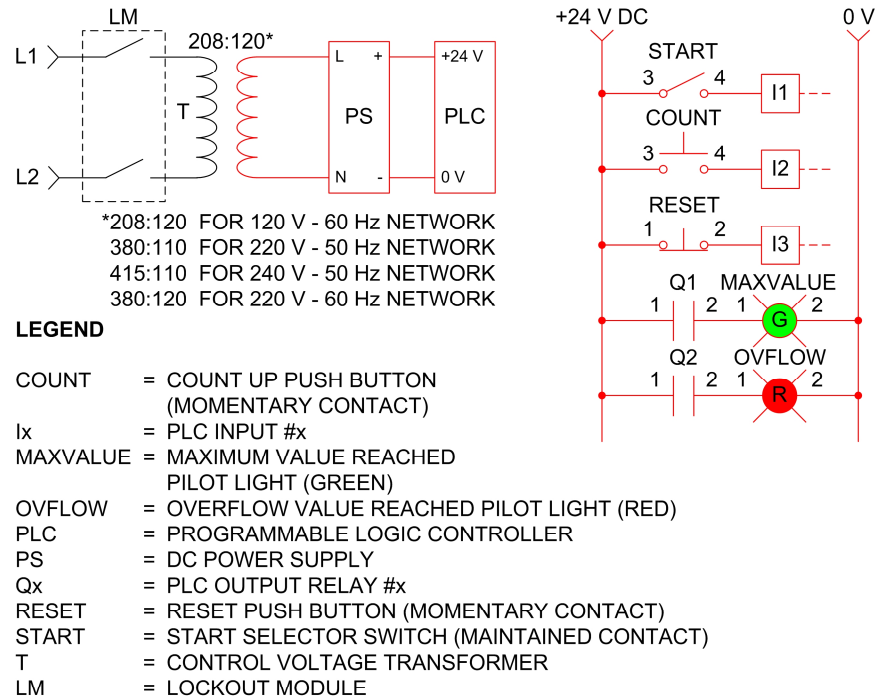


Figure 1-27. Connection diagram of the PLC counter and comparator circuit.

- ☐ 6. Set the START switch to the O position.

Perform the Energizing procedure.

**Note:** Make sure that the PLC is set to the RUN mode.

- ☐ 7. In your PLC program, what are the necessary conditions for the green pilot light to turn on?

---



---

- ☐ 8. What are the necessary conditions for the red pilot light to start flashing?

---



---

- ☐ 9. Set the START selector switch to the L position.

- ☐ 10. Press the COUNT push button five times. The green pilot light will illuminate. In your program, which contact closes at the count of 5?

☐ A1    ☐ C1    ☐ T1

- ☐ 11. Press the COUNT push button another five times. The red pilot light will start flashing.

- ☐ 12. In your program, which contact closes at the count of 10?

☐ A1    ☐ C1    ☐ T1

- ☐ 13. In your program, which contact opens and closes alternately?

☐ A1    ☐ C1    ☐ T1

- ☐ 14. Access the counter 1 parameter display.

Set the START selector to switch to the O position, and then back to the L position.

What is the value of the counter retained (as shown on the counter parameter display)?

---

- ☐ 15. Press the RESET push button. What is now the value of the counter?

---

- ☐ 16. Set the PLC to the STOP mode.

Turn the individual power switch of the AC Power Supply off, disconnect the circuit, and return the equipment to the storage location.

## CONCLUSION

In this exercise, you used PLC comparator and counter functions to switch pilot lights following count events.

In the ladder program, a counter coil was actuated after 5 count pulses to light on a green pilot light. The counter accumulated value was increased by count pulses provided by a push button and reset by actuating the reset coil of the counter. At the count of ten, a comparator caused the red pilot light to start flashing alternately, due to a timer function.

### REVIEW QUESTIONS

1. Which of the following PLC instructions are counter coil functions?
  - a. Counter input (C)
  - b. Counting direction (D)
  - c. Counter Reset (R)
  - d. All of the above are correct.
  
2. What happens when the PLC counter setpoint is reached?
  - a. The counter's brake contact closes.
  - b. The counter's make contact closes.
  - c. The counter's actual value is reset.
  - d. None of the above is correct.
  
3. What happens when the PLC counter counts over the maximum value of 32 000?
  - a. The actual value is reset to 0.
  - b. The count direction is changed.
  - c. The value of 32 000 is retained.
  - d. None of the above is correct.
  
4. Where can test values of a PLC comparator function come from?
  - a. Counter relay
  - b. Timing relay
  - c. Set value (constant)
  - d. All of the above are correct.
  
5. When is the EQ comparator instruction true?
  - a. When I1 is lower than I2.
  - b. When I1 is not equal to I2.
  - c. When I1 is equal to I2.
  - d. When I1 is greater than I2.





# Unit Test

1. Which devices can be replaced by a PLC?
  - a. Timing relay
  - b. Counter relay
  - c. Control relay
  - d. All of the above are correct.
  
2. What can we compare the PLC break instructions to?
  - a. Set instruction
  - b. NO contacts
  - c. NC contacts
  - d. Parallel rung
  
3. By what means can a PLC be programmed?
  - a. Dedicated buttons on the PLC
  - b. Handheld terminal
  - c. Separate computer
  - d. All of the above are correct.
  
4. How is the "brain" section of the PLC called?
  - a. Processor section
  - b. Programming section
  - c. Power supply
  - d. Input/output section
  
5. Which programming method involves cutting a ladder program rung into sections to circumvent a PLC rung length limitation?
  - a. Using a marker
  - b. Using equivalent Boolean logic circuit
  - c. Using backwards wiring
  - d. All of the above are correct.
  
6. What is the name of the time PLCs take to process an entire circuit diagram?
  - a. Drop-out time
  - b. Pick-up time
  - c. Cycle time
  - d. Scan time

7. When is a delay produced with an on and off delay timing relay instruction?
  - a. After relay trigger coil becomes true or false
  - b. After relay trigger coil becomes true
  - c. After relay trigger coil becomes false
  - d. After relay stop coil becomes true or false
  
8. What has to be done to slightly modify a PLC control process?
  - a. Replace the PLC
  - b. Reprogram the PLC
  - c. Rewire the entire process
  - d. None of the above are correct.
  
9. When does the PLC counter instruction increment its actual value by one count?
  - a. When the counter rung makes a true-to-false transition.
  - b. When the counter rung makes a false-to-true transition.
  - c. When the counter rung remains energized for at least one second.
  - d. None of the above is correct.
  
10. When is the GT comparator instruction true?
  - a. When I2 is lower than I1
  - b. When I2 is not equal to I1
  - c. When I2 is equal to I1
  - d. When I2 is greater than I1

## PLC Control Circuits

### UNIT OBJECTIVE

Upon completion of this unit, you will be able to interface AC and DC voltages within a motor starter circuit. You will also be able to implement PLC motor starters enabling reversing, jogging, and overload control.

### DISCUSSION OF FUNDAMENTALS

A motor circuit can be made of subcircuits operating at different voltages. In the Industrial Controls Training System, there can be three different voltages:

- AC supply voltage from the AC Power Supply;
- AC control voltage from the Control Transformer;
- DC control voltage from the DC Power Supply.

Low AC and DC voltages are mainly used in control circuits to provide a safer working environment for the operator. A "bridge" must however be implemented between low and high voltage circuits. This bridge allows control devices to have an effect in a power circuit and feedback signals from the power circuit to be received by the control circuit.

In the manual *Basic Controls*, you have seen that the coil of a contactor can be actuated with AC control (low) voltage. You have also seen that the NO power contacts of the same contactor can switch motor supply (high) voltage on and off. This example shows that a relay-type device can take a signal of a given voltage to have an effect on a circuit of a different voltage. Relay-type devices can therefore act as bridges between two subcircuits operating at different voltages.

The same principle applies to the Interposing Relays module, Model 3129. This device provides a way of bridging AC and DC control voltages in both ways (AC to DC and DC to AC). This feature is useful in applications where the 24 V dc PLC interacts with the system's AC devices.

### **Motor Control Circuits using a PLC**

PLCs can replace wired logic. When changes are made to a control circuit, there is usually not much rewiring necessary, except connecting the new devices to the PLC. The main job typically consists of modifying the PLC program.

In the manual *Basic Controls*, you implemented various motor control circuits to run or jog a motor in forward or reverse direction. Exercises 2 and 3 will concentrate on presenting alternative ways of implementing these circuits with the help of a PLC. The last exercise will also deal with the way to handle a motor overload condition within a PLC circuit.

## Interfacing Voltages

### EXERCISE OBJECTIVE

- Interface DC and AC voltages within a motor starter circuit.

### DISCUSSION

In a single motor control circuit, some components may work at different voltages. For example, in the Industrial Controls Training System, the Programmable Logic Controller module operates at 24 V dc, whereas the Selector Switches module requires AC control voltage and the Brake Motor requires higher AC voltage.

The Interposing Relays module, Model 3129, ensures compatibility and logical continuity between 24 V dc and 110/120 V ac circuits. This module, shown in Figure 2-1, includes six relays: three for AC to DC (IR1, IR2, IR3) and three for DC to AC (IR4, IR5, IR6) logical conversion.

The terminals of the Interposing Relays module are as follows:

- Terminals A1-A2: supply voltage;
- Terminals 11-12: NC contacts;
- Terminals 11-14: NO contacts.

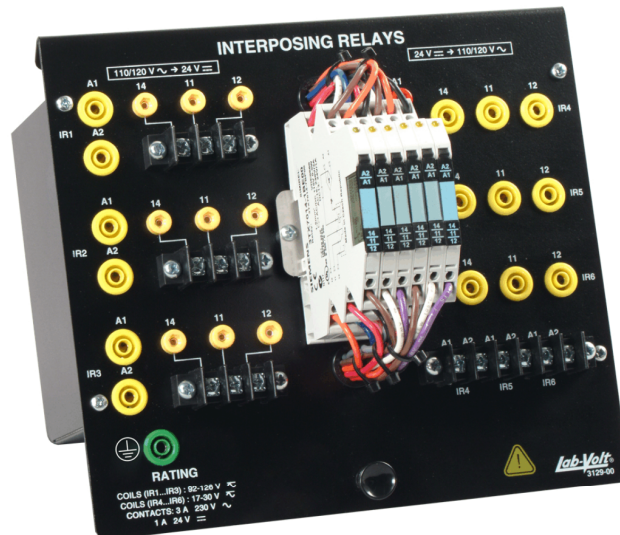
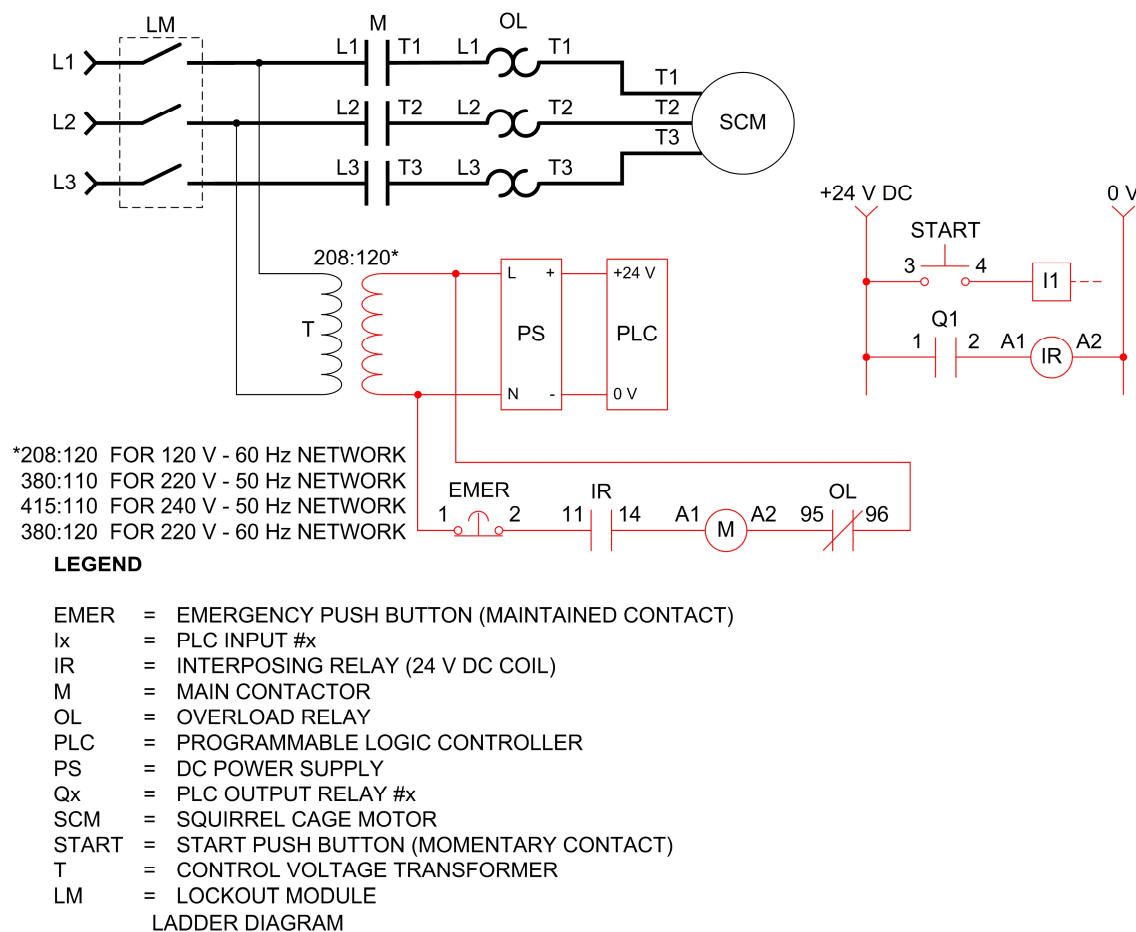


Figure 2-1. Interposing Relays, Model 3129.

Figure 2-2 shows how a 24 V dc control signal is transmitted from the Programmable Logic Controller module to the motor starting contactor through an interposing relay.

When the START push button is pressed, coil Q1 is energized, closing its related NO contact (Q1 terminals 1-2). This causes the interposing coil IR (DC coil) to be energized, closing its related NO contact (IR terminals 11-14). Because a 110/120 V ac source is connected to one end of the NO contact, a 110/120 V ac control signal is now provided at the other end of the contact. This last signal may, for instance, be used to start the motor via an AC contactor.



**Figure 2-2. DC to AC conversion connection diagrams.**

Figure 2-3 shows how a 110/120 V ac signal can be read by the PLC. When the motor is running, the power contacts of the contactor are closed, and therefore its NO contact (M terminals 13-14) is also closed. The 110/120 V ac voltage connected to one end of the NO contact is then provided at the other end of the contact, which is connected to the A1 terminal of the interposing relay IR. Because the A2 terminal of the relay IR is linked to the neutral line, the relay coil energizes, closing the corresponding NO contact. A 24 V dc signal, provided by the DC Power Supply, is then relayed to the PLC input.

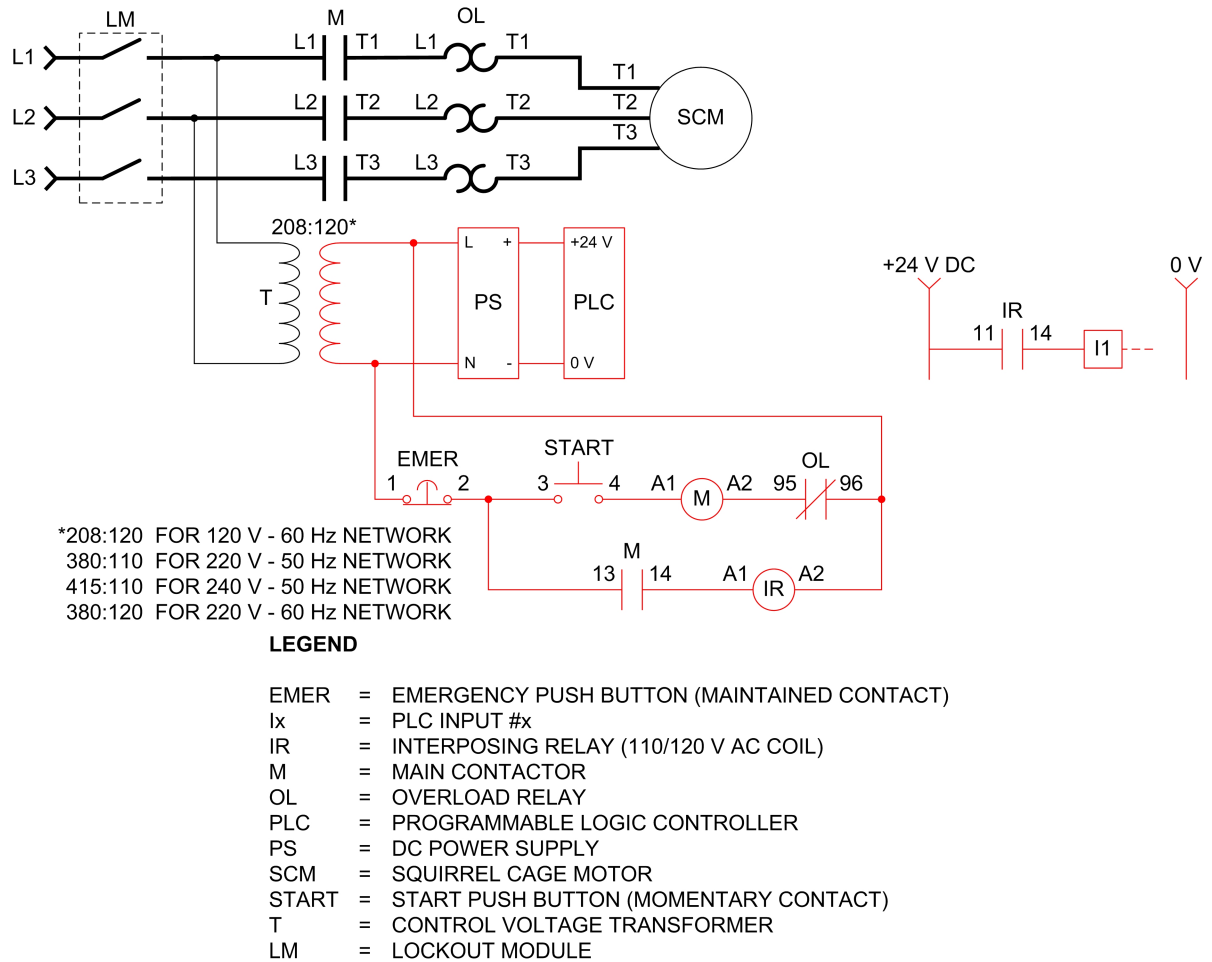


Figure 2-3. AC to DC conversion connection diagrams.



### Procedure Summary

In this exercise, you will set up a basic motor control circuit (Figure 2-5) commanded by DC controls through a PLC.

In this circuit, when the START push button is pressed, an input signal is provided to the PLC. The PLC program uses this signal to activate an interposing relay connected to one of its outputs. This interposing relay in turn triggers the AC contactor to start the motor.

On the other hand, the NO contact of the contactor provides feedback to the DC subcircuit. When closed, this contact provides a PLC input signal via an AC to DC interposing relay. The PLC program reads this signal to turn on the RUN pilot light and to keep the motor running continuously.

Finally, the STOP push button, when pressed, de-energizes the motor circuit. When the RUN pilot light is off, the STOPL pilot light is on.

### EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

### PROCEDURE



The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

#### Basic setup

- ☐ 1. Perform the Basic Setup procedure.

#### Basic motor control circuit commanded by DC controls through a PLC

- ☐ 2. Connect the Programmable Logic Controller module as described in Exercise 1-1.

Perform the Energizing procedure.

Enter the program shown in Figure 2-4.

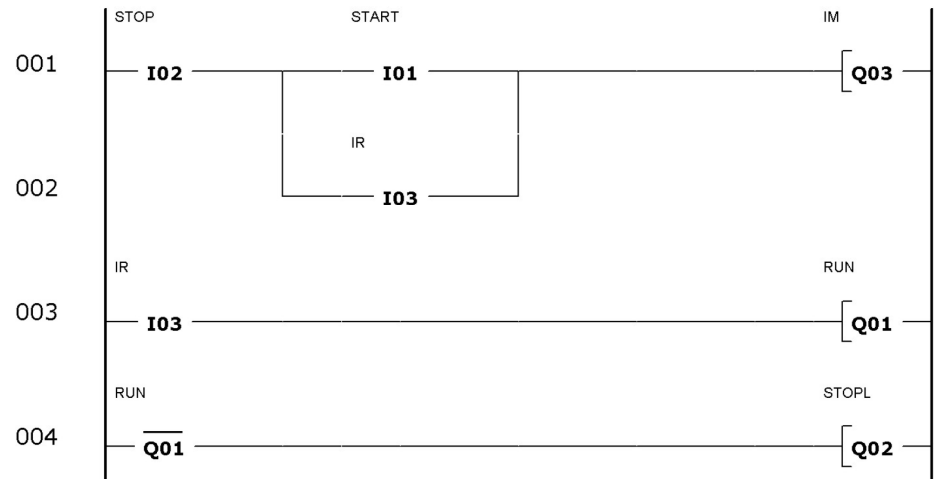
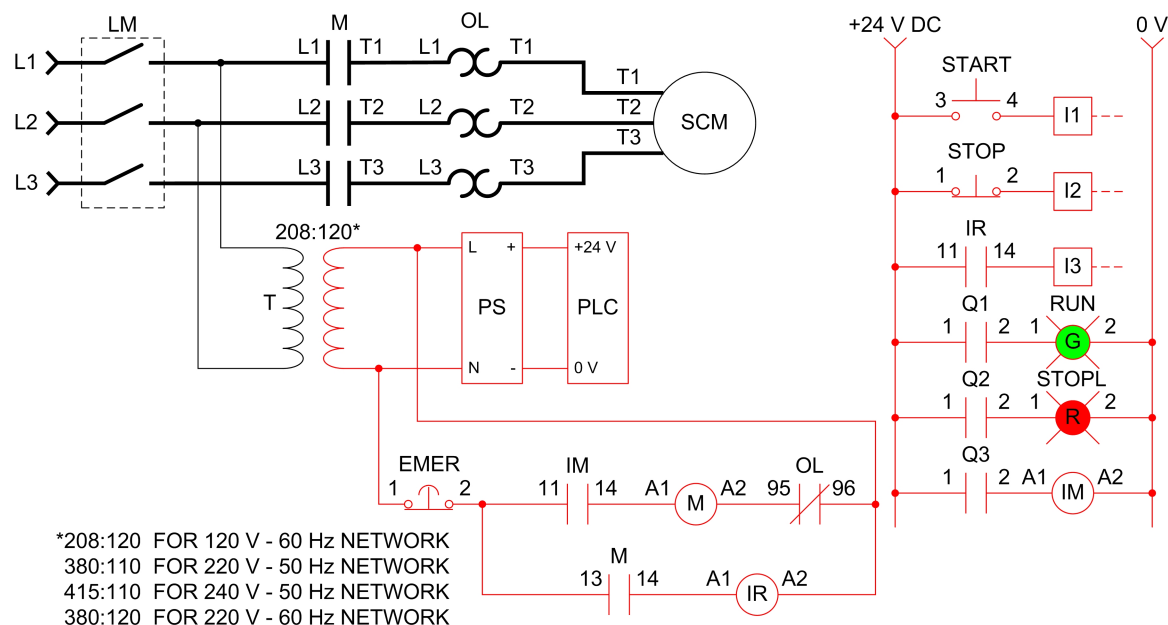


Figure 2-4. Basic motor control ladder program.

- ☐ 3. Install the Brake Motor, and Security Guard.

Set up the circuit shown in Figure 2-5.

Do not turn on the Lockout Module for now.



### LEGEND

EMER	=	EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
Ix	=	PLC INPUT #x
IR	=	INTERPOSING RELAY (110/120 V AC COIL)
IM	=	INTERPOSING RELAY FOR MAIN CONTACTOR (24 V DC COIL)
M	=	MAIN CONTACTOR
OL	=	OVERLOAD RELAY
PLC	=	PROGRAMMABLE LOGIC CONTROLLER
PS	=	DC POWER SUPPLY
Qx	=	PLC OUTPUT RELAY #x
RUN	=	RUN PILOT LIGHT (GREEN)
SCM	=	SQUIRREL CAGE MOTOR
START	=	START PUSH BUTTON (MOMENTARY CONTACT)
STOP	=	STOP PUSH BUTTON (MOMENTARY CONTACT)
STOPL	=	STOP PILOT LIGHT (RED)
T	=	CONTROL VOLTAGE TRANSFORMER
LM	=	LOCKOUT MODULE

**Figure 2-5. Basic motor control connection diagrams.**

- ☐ 4. Fill out the Anticipated Status section of Table 2-1. Refer to the description of the circuit found in the PROCEDURE SUMMARY section to predict the status of the inputs and outputs, depending on the circuit operating mode.

CONTACT/COIL DESCRIPTION		ANTICIPATED STATUS			
		RUNNING MODE (MOTOR ON, NO PUSH BUTTON PRESSED)		STOPPED MODE (MOTOR OFF, NO PUSH BUTTON PRESSED)	
		ON	OFF	ON	OFF
I1	Start make contact				
I2	Stop brake contact				
I3	Motor run input				
Q1	Run pilot light				
Q2	Stop pilot light				
Q3	Motor output				

Table 2-1. Status of the contacts and coils in running and stopped modes.

- ☐ 5. Perform the Energizing procedure.

**Note:** Make sure that the PLC is set to the RUN mode.

- ☐ 6. Press the START push button. Is the I1 input energized while you press the START push button?

☐ Yes      ☐ No

- ☐ 7. Does the motor start?

☐ Yes      ☐ No

- ☐ 8. Verify that the circuit works in the RUNNING mode as predicted in Table 2-1. Does the circuit work as predicted?

☐ Yes      ☐ No

- ☐ 9. Where does the holding contact in the PLC program of Figure 2-4 come from? Refer to Figure 2-5 if necessary.

---



---

- ☐ 10. What is the purpose of the PLC program holding contact?

---

---

- ☐ 11. Press the STOP push button. Is the I2 input energized while you press the STOP push button?

☐ Yes      ☐ No

- ☐ 12. Does the motor stop?

☐ Yes      ☐ No

- ☐ 13. Verify that the circuit works in the STOPPED mode as predicted in Table 2-1. Does the circuit work as predicted?

☐ Yes      ☐ No

- ☐ 14. Explain how the contactor coil (M) is linked to the PLC output Q3. Refer to Figures 2-4 and 2-5 if necessary.

---

---

---

- ☐ 15. Set the PLC to the STOP mode.

Turn the individual power switch of the AC Power Supply off, disconnect the circuit, and return the equipment to the storage location.

## CONCLUSION

In this exercise, you used a PLC to control a motor. Because the PLC and the motor circuits operate at different voltages, you used interposing relays to make them interact with each other.

### REVIEW QUESTIONS

1. In Figure 2-4 ladder program, which contact is part of the motor holding circuit?
  - a. I1
  - b. I3
  - c. Q1
  - d. Q3
  
2. When are interposing relays useful?
  - a. When two subcircuits operate at different voltages.
  - b. Every time control and motor circuits are connected.
  - c. When a different voltage has to be produced from a given voltage.
  - d. None of the above is correct.
  
3. In the Figure 2-5 connection diagram, which voltage type is connected to the motor terminals?
  - a. DC Power Supply voltage
  - b. AC Power Supply line-neutral voltage
  - c. AC Power Supply line-line voltage
  - d. None of the above is correct.
  
4. Refer to Figure 2-5. To what device is PLC input I3 directly connected?
  - a. Push button
  - b. Selector switch
  - c. Contactor
  - d. Interposing relay
  
5. If an interposing relay is connected to a device providing an incoming signal, which part of the interposing relay will be receiving this incoming signal?
  - a. Relay coil
  - b. Relay NC contact
  - c. Relay NO contact
  - d. It depends on the situation.



## Motor Starters with Jogging

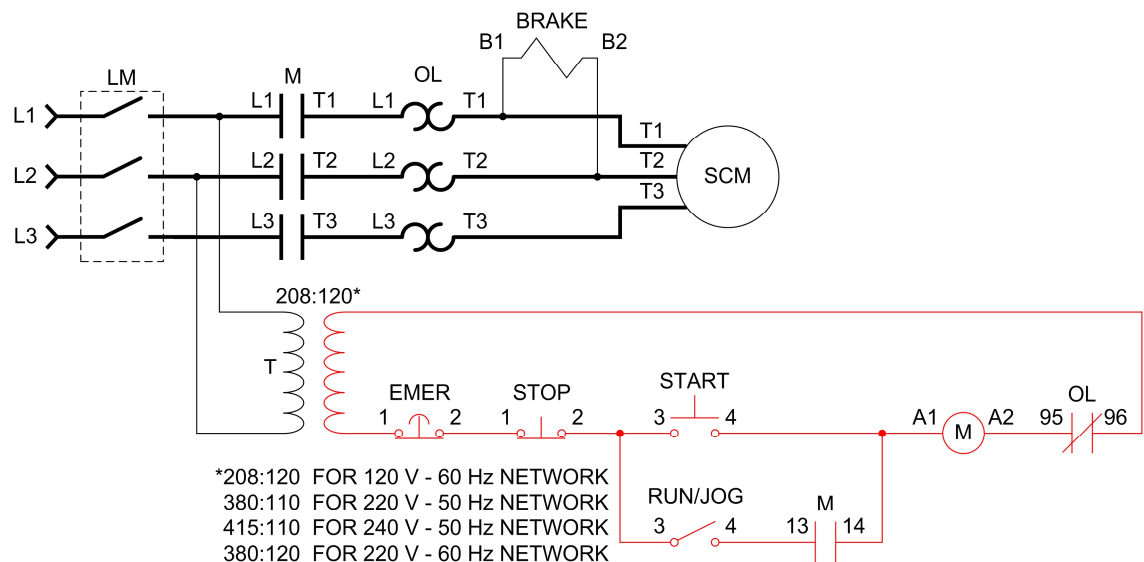
### EXERCISE OBJECTIVE

- Implement motor starter circuits with jogging to demonstrate the flexibility of PLCs.

### DISCUSSION

PLCs can be configured in a variety of ways. The use of PLCs in motor control circuits has the advantage of allowing changes to the circuit easily, without much rewiring. This is particularly useful when new features or controls must be added to the circuit. In the manual *Basic Controls*, you implemented two different motor jogging circuits:

- A circuit where a selector switch enables alternation between the running and the jogging modes (see Figure 2-6).



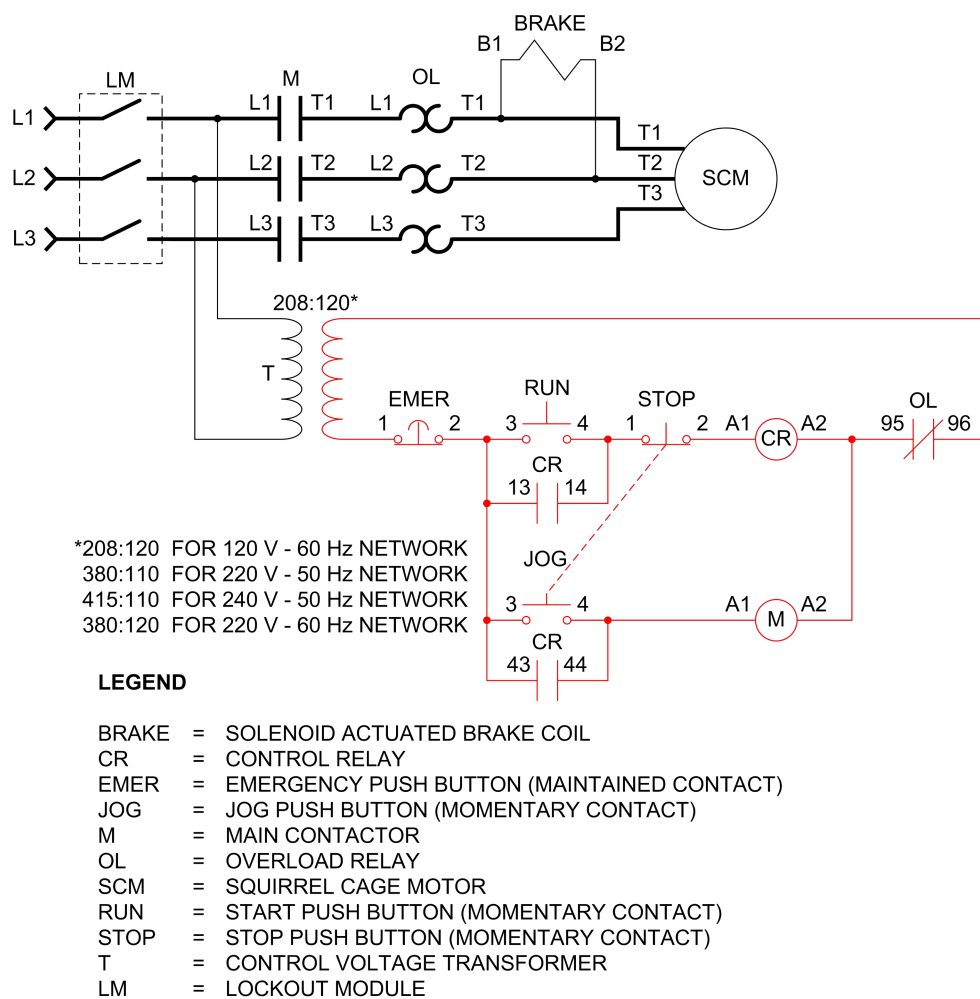
### LEGEND

BRAKE	= SOLENOID ACTUATED BRAKE COIL
EMER	= EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
M	= MAIN CONTACTOR
OL	= OVERLOAD RELAY
RUN/JOG	= RUN/JOG SELECTOR SWITCH (MAINTAINED CONTACT)
SCM	= SQUIRREL CAGE MOTOR
START	= START PUSH BUTTON (MOMENTARY CONTACT)
STOP	= STOP PUSH BUTTON (MOMENTARY CONTACT)
T	= CONTROL VOLTAGE TRANSFORMER
LM	= LOCKOUT MODULE

Figure 2-6. Jog/Run circuit with selector switch.



- A circuit where push buttons and a control relay are used to control the run and jog functions independently (see Figure 2-7).



**Figure 2-7. Jogging circuit with control relay.**

In a situation where a circuit has to be modified after it has been implemented, a PLC really is very useful.

### Procedure Summary

In the first part of this exercise, you will be asked to set up a JOG/RUN circuit where the position of a selector switch makes the START push button work in the run or jog mode. Both the EMERGENCY and JOG/STOP push buttons make the motor stop.

In the second part of the exercise, your client wants you to put into operation a circuit where two push buttons are used: START and JOG/STOP. In this circuit, when the motor is at rest, the JOG/STOP pushbutton makes the motor start momentarily. Both the EMERGENCY and JOG/STOP push buttons make the motor stop. To obtain this circuit from the last one, all you will have to do is to modify the inputs and the ladder program of the PLC.

### EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

### PROCEDURE



The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

#### Basic setup

- ☐ 1. Perform the Basic Setup procedure.

#### Jog/Run with selector switch

- ☐ 2. Connect the Programmable Logic Controller module as described in Exercise 1-1.

Perform the Energizing procedure.

Enter the program shown in Figure 2-8.

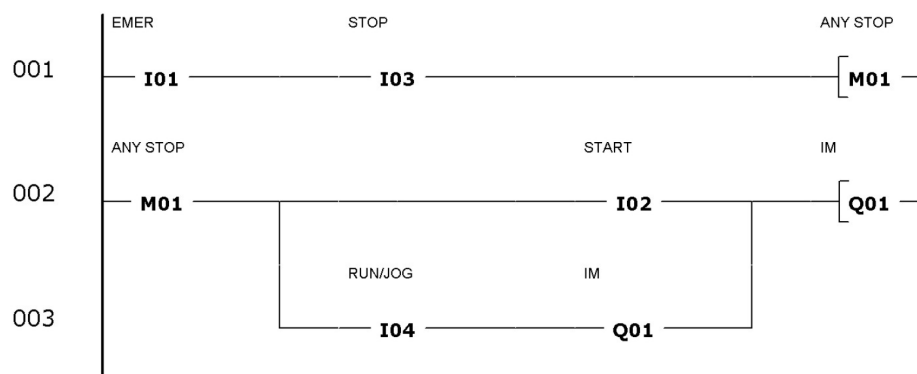


Figure 2-8. Jog/Run with selector switch ladder program.

Perform the Lockout/Tagout procedure.

- ☐ 3. Install the Brake Motor, Inertia Wheel, and Security Guard.

Set up the circuit shown in Figure 2-9.

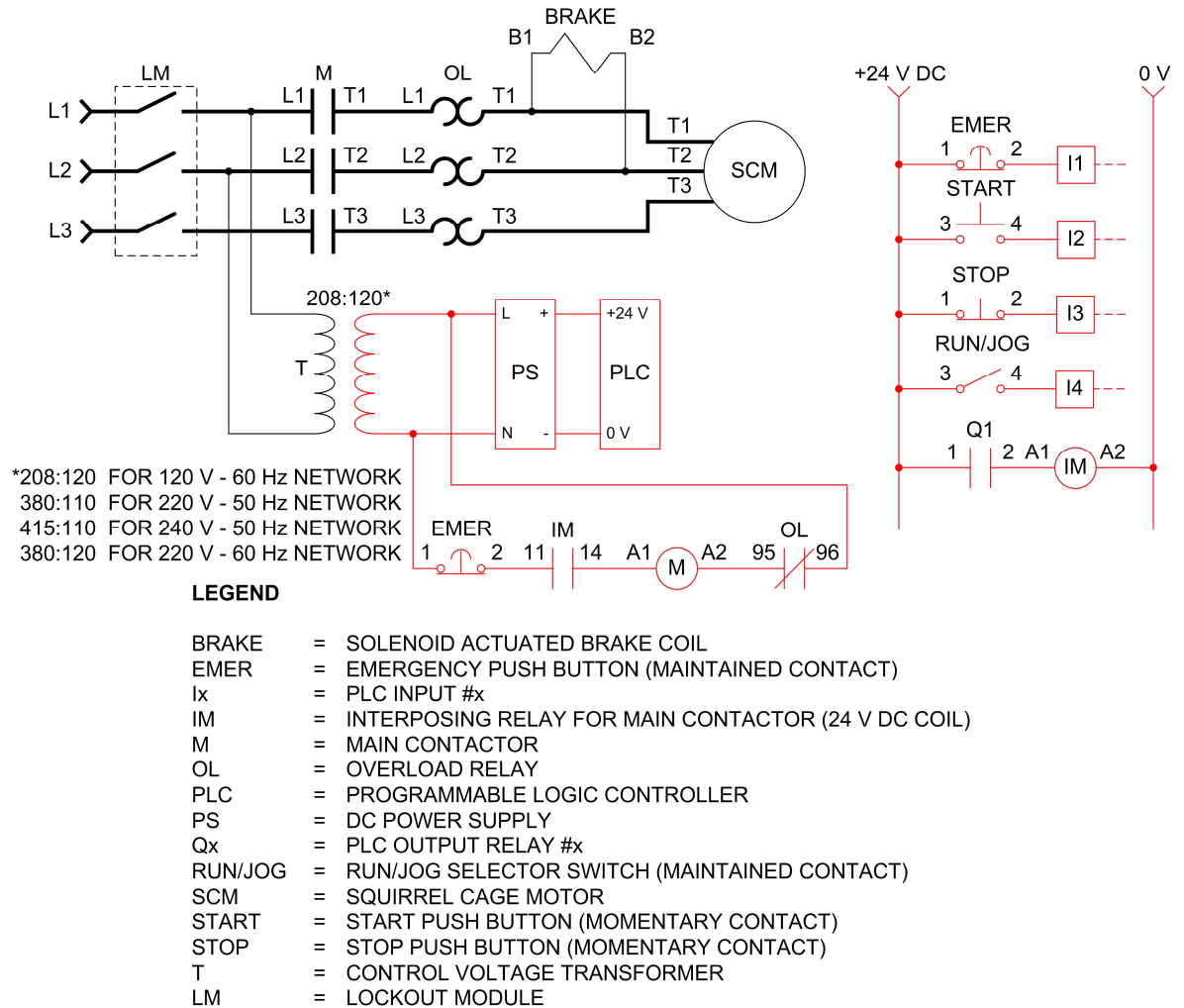


Figure 2-9. Jog/Run with selector switch connection diagrams.

Set the JOG/RUN selector switch to the O position (JOG).

Perform the Energizing procedure.

**Note:** Make sure that the PLC is set to the RUN mode.

☐ 4. Which PLC inputs/outputs are energized?

☐ I1    ☐ I2    ☐ I3    ☐ I4    ☐ Q1

- ☐ 5. Press the START push button. Which PLC's inputs/outputs are energized while the START push button is pressed?
- ☐ I1    ☐ I2    ☐ I3    ☐ I4    ☐ Q1
- ☐ 6. Which PLC's inputs/outputs are energized after the START push button is released?
- ☐ I1    ☐ I2    ☐ I3    ☐ I4    ☐ Q1
- ☐ 7. Does latching occur?
- ☐ Yes    ☐ No
- ☐ 8. Set the JOG/RUN selector switch to the L position (RUN).
- Which PLC's inputs/outputs are energized?
- ☐ I1    ☐ I2    ☐ I3    ☐ I4    ☐ Q1
- ☐ 9. Press the START push button. Which PLC's inputs/outputs are energized while the START push button is pressed?
- ☐ I1    ☐ I2    ☐ I3    ☐ I4    ☐ Q1
- ☐ 10. Which PLC's inputs/outputs are energized after the START push button is released?
- ☐ I1    ☐ I2    ☐ I3    ☐ I4    ☐ Q1
- ☐ 11. Does latching occur?
- ☐ Yes    ☐ No
- ☐ 12. Does the selector switch control the operating mode (JOG or RUN) of the START push button?
- ☐ Yes    ☐ No
- ☐ 13. Press the STOP push button to stop the Brake Motor.

- ☐ 14. Set the Programmable Logic Controller module to the STOP mode.

### Jog/Run with independent push buttons

- ☐ 15. Enter the program shown in Figure 2-10.

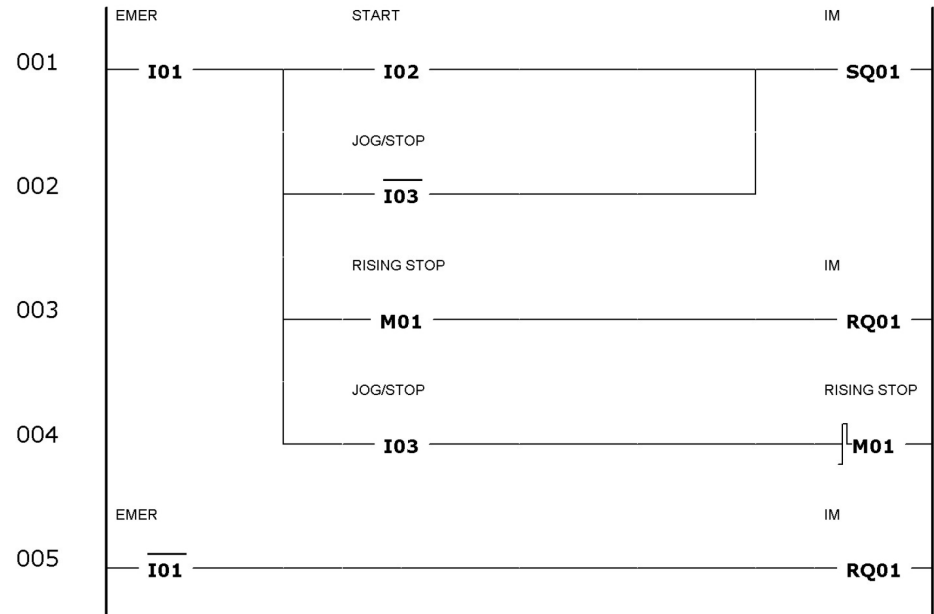


Figure 2-10. Jog/Run with independent push buttons ladder program.

- ☐ 16. Perform the Lockout/Tagout procedure.

Connect the PLC inputs and outputs according to Figure 2-11.

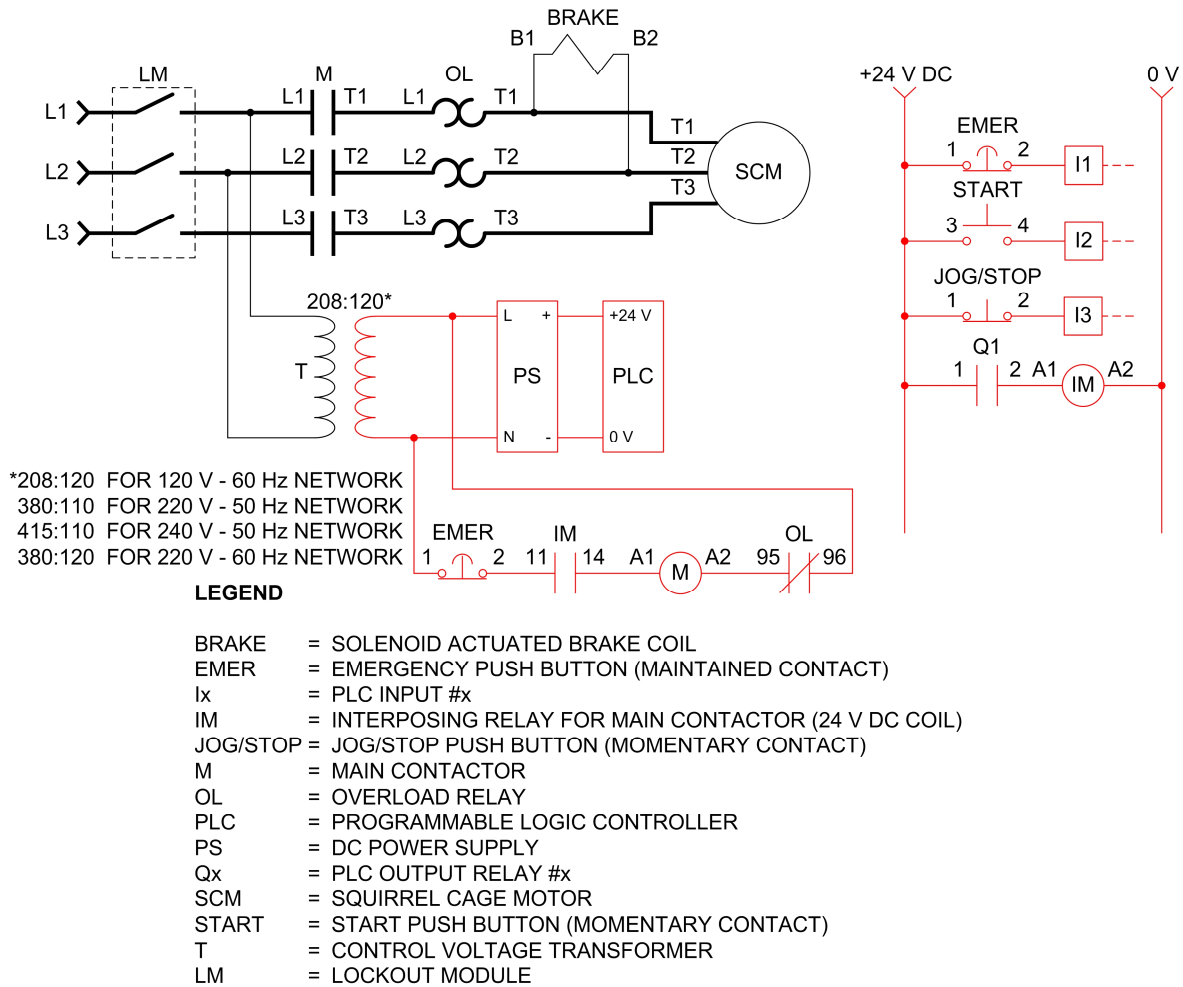


Figure 2-11. Jog/Run circuit with independent push buttons connection diagrams.

- ☐ 17. If you refer to Figures 2-9 and 2-11, do you have to change any other connection than the PLC inputs to convert the last circuit into the new one?

☐ Yes      ☐ No

- ☐ 18. Perform the Energizing procedure.

- ☐ 19. Set the Programmable Logic Controller module to the RUN mode.

- ☐ 20. Which PLC's inputs/outputs are energized?
- ☐ I1      ☐ I2      ☐ I3      ☐ Q1
- ☐ 21. Press the START push button. Which PLC's inputs/outputs are energized while the START push button is pressed?
- ☐ I1      ☐ I2      ☐ I3      ☐ Q1
- ☐ 22. Which PLC's inputs/outputs are energized after the START push button is released?
- ☐ I1      ☐ I2      ☐ I3      ☐ Q1
- ☐ 23. Does latching occur?
- ☐ Yes      ☐ No
- ☐ 24. Press and release the JOG/STOP push button. Which PLC's inputs/outputs are energized?
- ☐ I1      ☐ I2      ☐ I3      ☐ Q1
- ☐ 25. Which PLC's inputs/outputs are energized while the JOG/STOP push button is pressed?
- ☐ I1      ☐ I2      ☐ I3      ☐ Q1
- ☐ 26. Which PLC's inputs/outputs are energized after the JOG/STOP push button is released?
- ☐ I1      ☐ I2      ☐ I3      ☐ Q1
- ☐ 27. Does latching occur?
- ☐ Yes      ☐ No
- ☐ 28. Is the JOG/STOP push button independent from the START push button?
- ☐ Yes      ☐ No



- ☐ 29. Set the PLC to the STOP mode.

Turn the individual power switch of the AC Power Supply off, disconnect the circuit, and return the equipment to the storage location.

## CONCLUSION

In this exercise, you used a PLC to implement two motor JOG/RUN circuits. These circuits operated in the same manner as their hardwired counterparts. However, changing from one circuit to another required much less rewiring; only the PLC program and the inputs were changed.

## REVIEW QUESTIONS

1. What advantages does a PLC circuit have over a hardwired circuit?
  - a. Configurability
  - b. Ease of expandability
  - c. Less hardwiring
  - d. All of the above are correct.
2. What are the differences between the connection diagrams in Figures 2-9 and 2-11?
  - a. PLC inputs
  - b. PLC outputs
  - c. Schematic diagrams
  - d. All of the above are correct.
3. In the Figure 2-8 ladder program, which programming method was used to circumvent the PLC rung length limitation?
  - a. Using a marker
  - b. Using equivalent Boolean logic circuit
  - c. Using backwards wiring
  - d. None of the above is correct.
4. In the Figure 2-10 ladder program, which programming unit is the logical equivalent of the Control Relay in Figure 2-7?
  - a. RQ1
  - b. I3
  - c. SQ1
  - d. M1

5. In the Figure 2-8 ladder program, under which circumstance is the motor jogging?
- a. START push button is pressed.
  - b. State of the M marker is true.
  - c. JOG/RUN selector is at the JOG position.
  - d. All of the above are correct.



## Reversing Motor Starters with Jogging

### EXERCISE OBJECTIVE

- Implement a PLC reversing motor starter.
- Add a tripped overload relay light indicator to a circuit.

### DISCUSSION

Some applications, in particular in position control, require a motor to run and jog in both forward and reverse directions. To meet these requirements a jogging control circuit with a reversing motor starter can be implemented. Figure 2-12 is an example of a hardwired motor reversing circuit with jogging. This setup includes a control relay to form the holding circuits.



### Tripped overload indicator

An electric overload occurs when a motor draws a current that is above its nominal value. Standard motor starters include an overload relay that detects sustained, abnormally high currents to prevent damage to the motor. Under these irregular conditions, the overload relay trips, causing the motor to be de-energized.

The motor stopping and its origin might not be readily apparent to the operator. Therefore, a pilot light can be added into the motor control circuit to display the overload condition. Also, the overload signal can be used to keep the PLC from restarting the motor as soon as the overload relay is reset.

### Procedure Summary

In this exercise, you will set up a PLC motor reversing circuit with jogging capabilities. You will test that the ladder program, shown in Figure 2-13, functions like the hardwired circuit in Figure 2-12.

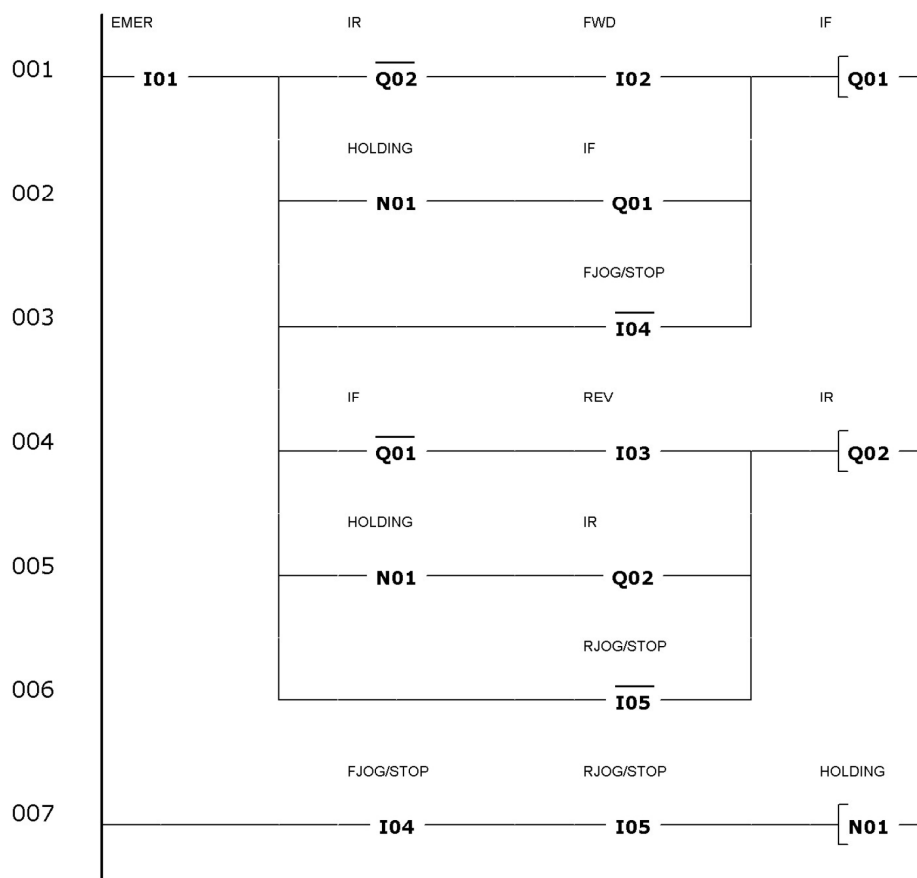
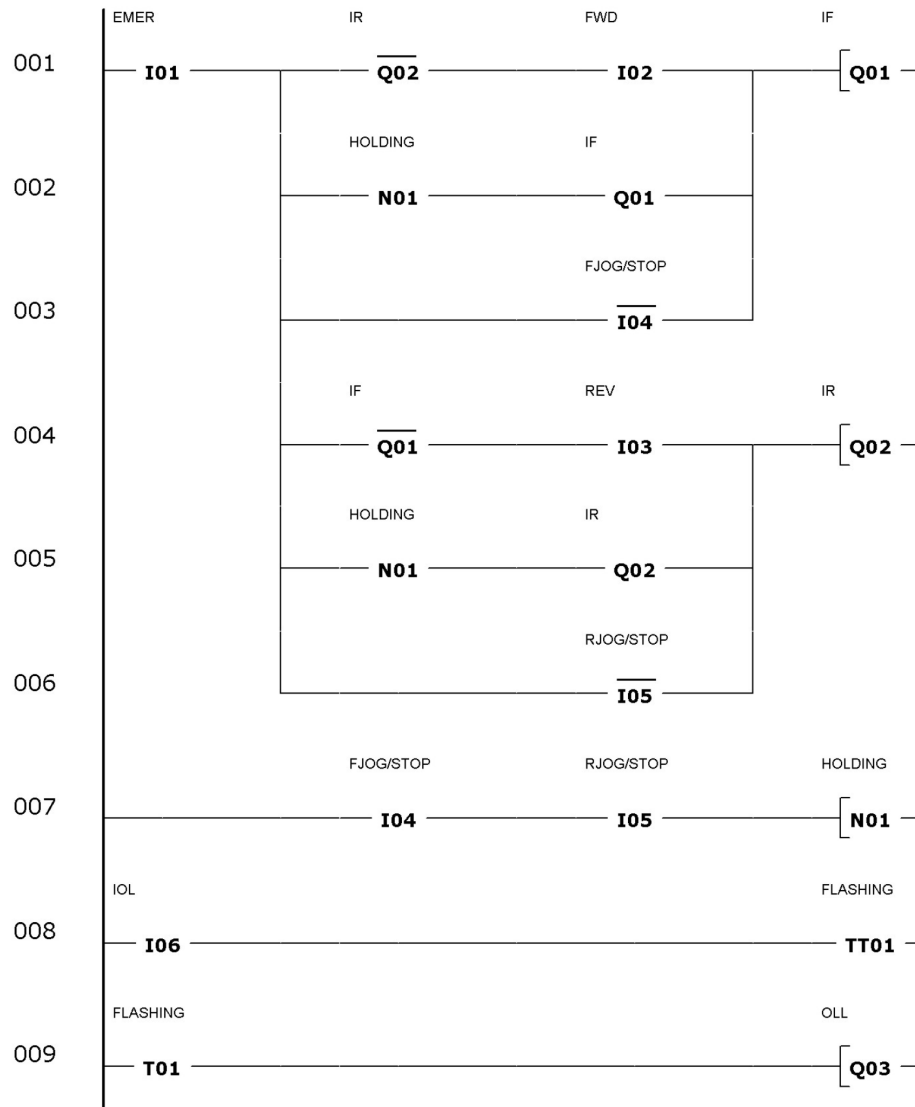


Figure 2-13. Reversing motor starter with jogging ladder program.

In the second part of the exercise, you will add a pilot light that uses the NO contact of the Overload Relay module to indicate the overload condition of the circuit. Figure 2-14 represents the new ladder program including an input for the NO contact of the Overload Relay module and an output for the pilot light. A timing relay is added to the program to make the pilot light flash.



**Figure 2-14. Reversing motor starter with jogging and overload indicator ladder program.**

To verify that this new feature functions correctly, you will use the Overload Relay's TEST button to simulate a motor overload condition. You will notice that the system can restart automatically if the overload signal is not used to reset the PLC program. To increase the system safety, you will modify your program so that an operation is required from the operator to restart the motor, following an overload.

## EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

## PROCEDURE

### **WARNING**



The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

### Basic setup

- ☐ 1. Perform the Basic Setup procedure.

### Reversing motor starter with jogging

- ☐ 2. Connect the Programmable Logic Controller module as described in Exercise 1-1.

Perform the Energizing procedure.

Enter the ladder program shown in Figure 2-13.

Perform the Lockout/Tagout procedure.

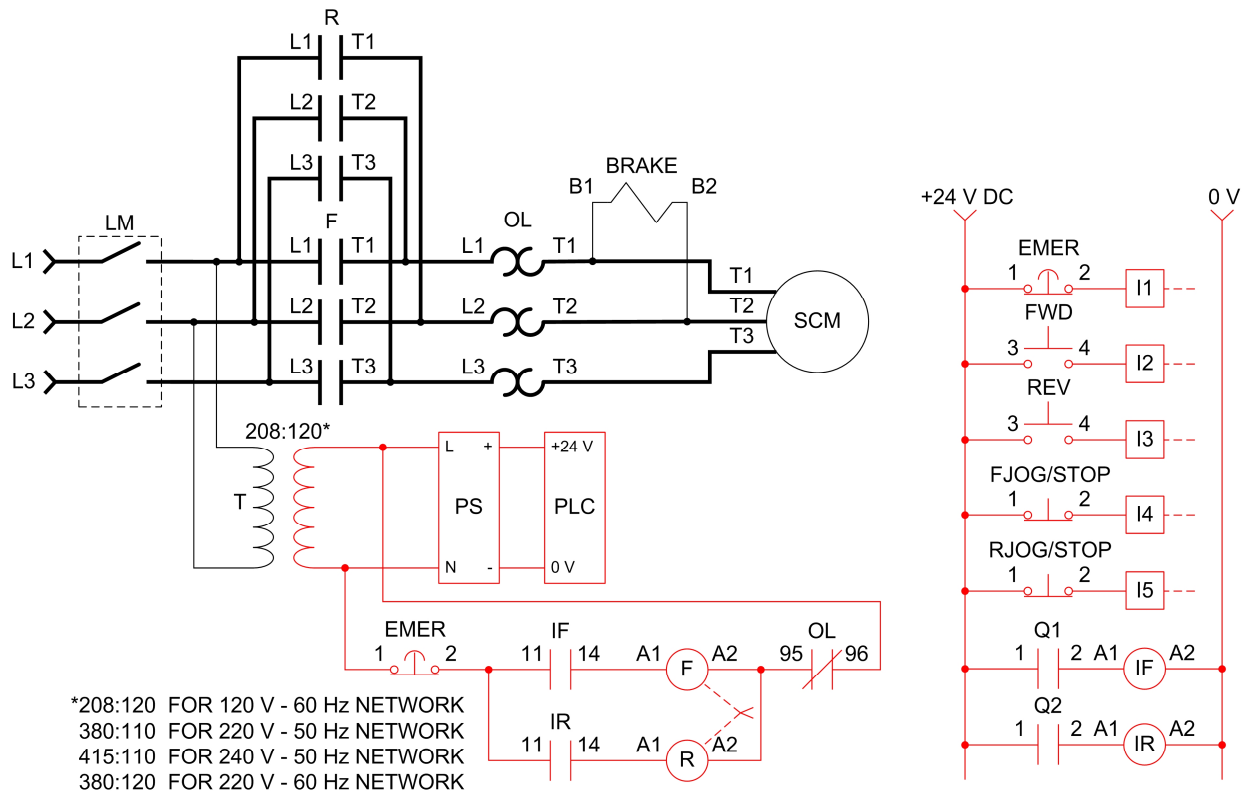
- ☐ 3. Install the Brake Motor, Inertia Wheel, and Security Guard.

Set up the circuit shown in Figure 2-15.

Perform the Energizing procedure.

**Note:** Make sure that the PLC is set to the RUN mode.





## LEGEND

BRAKE	=	SOLENOID ACTUATED BRAKE COIL
EMER	=	EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
F	=	FORWARD DIRECTION CONTACTOR
FJOG/STOP	=	FORWARD JOG/STOP PUSH BUTTON (MOMENTARY CONTACT)
FWD	=	FORWARD PUSH BUTTON (MOMENTARY CONTACT)
Ix	=	PLC INPUT #x
IF	=	INTERPOSING RELAY FOR FORWARD CONTACTOR (24 V DC COIL)
IR	=	INTERPOSING RELAY FOR REVERSE CONTACTOR (24 V DC COIL)
M	=	MAIN CONTACTOR
OL	=	OVERLOAD RELAY
PLC	=	PROGRAMMABLE LOGIC CONTROLLER
PS	=	DC POWER SUPPLY
Qx	=	PLC OUTPUT RELAY #x
R	=	REVERSE DIRECTION CONTACTOR
REV	=	REVERSE PUSH BUTTON (MOMENTARY CONTACT)
RJOG/STOP	=	REVERSE JOG/STOP PUSH BUTTON (MOMENTARY CONTACT)
SCM	=	SQUIRREL CAGE MOTOR
T	=	CONTROL VOLTAGE TRANSFORMER
LM	=	LOCKOUT MODULE

**Figure 2-15. PLC reversing motor starter with jogging circuit connection diagrams.**

- ☐ 4. Which PLC's inputs/outputs are energized?

☐ I1      ☐ I2      ☐ I3      ☐ I4      ☐ I5      ☐ Q1      ☐ Q2

- ☐ 5. Test the PLC circuit and note in Table 2-1 if it has the same characteristics as the hardwired version in Figure 2-12.

CHARACTERISTICS OF THE HARDWIRED CIRCUIT	PLC circuit	
	Yes	No
FWD button makes the motor run continuously		
REV button makes motor run continuously in reverse direction		
FJOG/STOP can make a motor running continuously (F and R) stop		
RJOG/STOP can make a motor running continuously (F and R) stop		
FJOG/STOP makes motor run only as long as it is pressed		
RJOG/STOP makes motor run in reverse direction only as long as it is pressed		
The EMER button de-energizes the control circuit until it is reset		

Table 2-1. Characteristics of the hardwired circuit.

- ☐ 6. What are  $\overline{Q1}$  and  $\overline{Q2}$  contacts used for in the ladder program?

---



---

- ☐ 7. Do your observations confirm that the PLC version is equivalent to the hardwired version in terms of functionalities?

☐ Yes      ☐ No

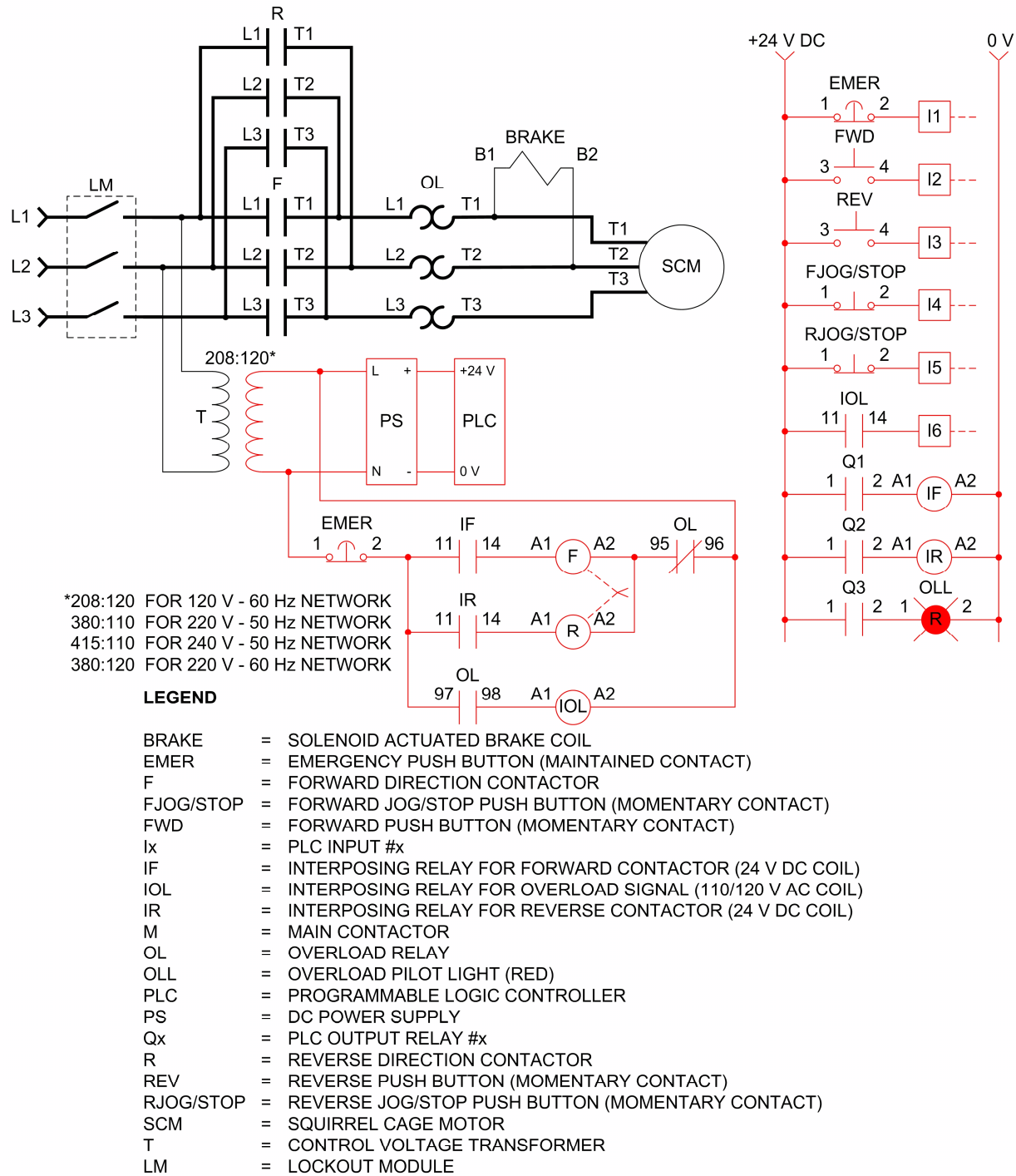
- ☐ 8. Set the Programmable Logic Controller module to the STOP mode.

Enter the program shown in Figure 2-14, with the following timing relay (T1) parameter values:

- Coil function: trigger
- Mode: flash switching
- Setpoint I1: 0.5 s
- Setpoint I2: 0.5 s

- ☐ 9. Perform the Lockout/Tagout procedure.

Set up the circuit according to Figure 2-16.



**Figure 2-16. Reversing motor starter with jogging and overload indicator connection diagrams.**

- ☐ 10. Perform the Energizing procedure.

**Note:** Make sure that the PLC is set to the RUN mode.

- ☐ 11. Which PLC's inputs/outputs are energized?

☐ I1    ☐ I2    ☐ I3    ☐ I4    ☐ I5    ☐ I6    ☐ Q1    ☐ Q2    ☐ Q3

- ☐ 12. Press the FWD push button. Does the motor start running continuously?

☐ Yes    ☐ No

- ☐ 13. Pull the red TEST button located on the Overload Relay module. This will simulate an overload condition where the Overload Relay is triggered.

Does the motor stop?

☐ Yes    ☐ No

- ☐ 14. Does the red OLL (overload) pilot light start flashing?

☐ Yes    ☐ No

- ☐ 15. Release the TEST button. Does the red OLL (overload) pilot light keep on flashing?

☐ Yes    ☐ No

- ☐ 16. Does the motor restart automatically?

☐ Yes    ☐ No

- ☐ 17. Set the PLC to the STOP mode.

To increase the system safety, modify the program according to Figure 2-17. This modification prevents the motor from automatically restarting.

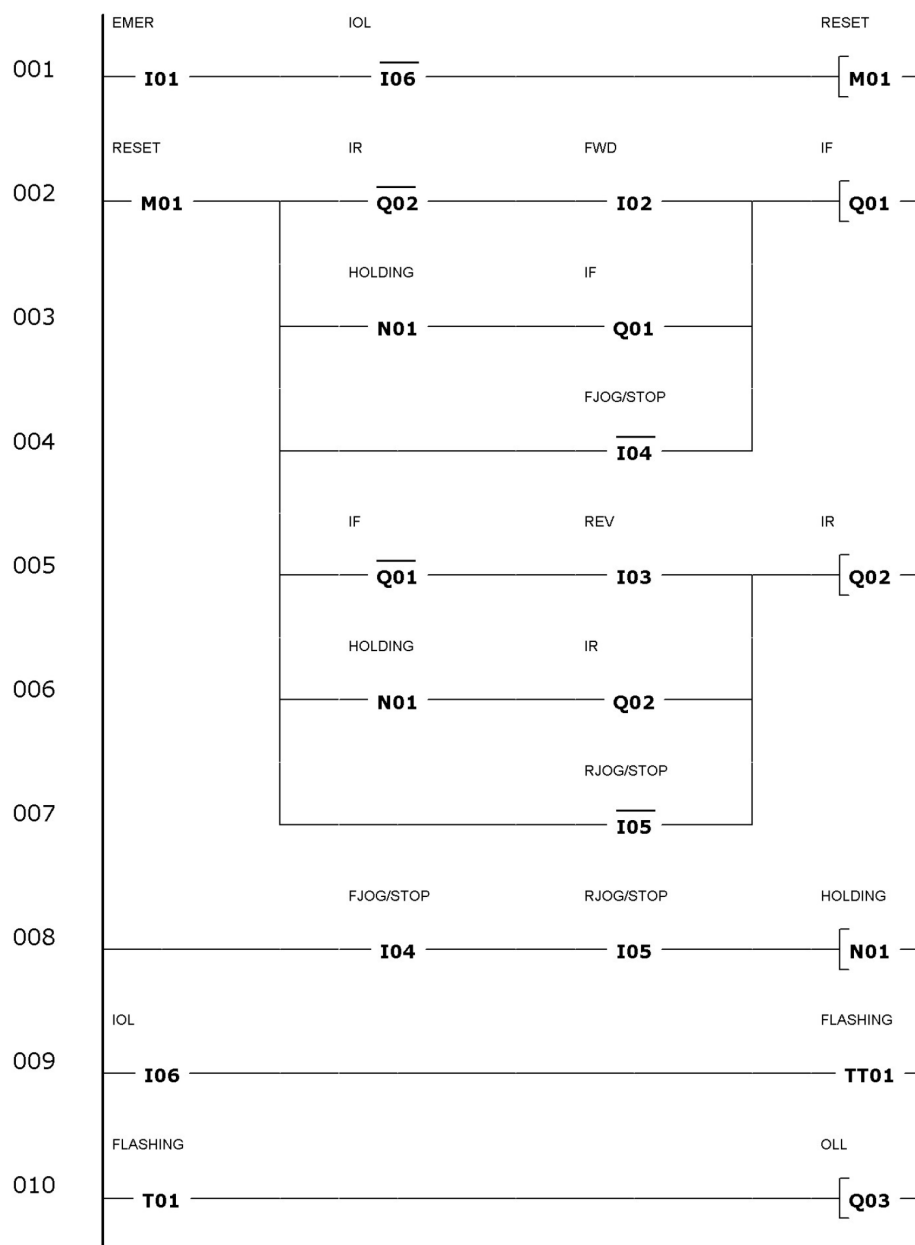


Figure 2-17. Reversing motor starter with jogging and overload indicator and reset connection diagrams.

- ☐ 18. Set the PLC to the RUN mode.

Press the FWD push button. Does the motor start running continuously?

☐ Yes      ☐ No

- ☐ 19. Simulate an overload condition by pulling the red TEST button of the Overload Relay module.

Does the motor stop and the red OLL (overload) pilot light start flashing?

☐ Yes      ☐ No

- ☐ 20. Release the TEST button. Does the red OLL (overload) pilot light keep on flashing?

☐ Yes      ☐ No

- ☐ 21. Does the motor restart automatically? Explain why.

---

---

---

- ☐ 22. Set the PLC to the STOP mode.

Turn the individual power switch of the AC Power Supply off, disconnect the circuit, and return the equipment to the storage location.

### CONCLUSION

In this exercise, you programmed three different ladder programs to obtain a reversing motor starter with jogging. The first program could run and jog in both directions. However, it did not provide any feedback from the Overload Relay module.

The second program was similar to the first one, except that the PLC had an input connected to the Overload Relay module to make a pilot light flash in case of an overload. But this setup caused the motor to restart as soon as the Overload Relay module was reset.

The third program prevents the motor from restarting automatically by unlatching the motor output (forward or reverse) when an overload condition is detected.

### REVIEW QUESTIONS

1. Which PLC programming unit in Figure 2-13 is logically equivalent to the control relay in Figure 2-12?
  - a. Q1
  - b. N1
  - c. Q2
  - d. I1
  
2. For what reason would a tripped overload pilot light be implemented in a motor control circuit?
  - a. To suggest the operator to stop the motor manually.
  - b. To make use of the overload relay NO contact.
  - c. Because the motor overload might not be readily apparent.
  - d. None of the above are correct.
  
3. Why is the circuit of Figures 2-14 and 2-15 likely to restart automatically, following an overload?
  - a. The PLC is powered continuously.
  - b. The signal from the overload relay NO contact does not reset the PLC program.
  - c. The overload relay can be reset automatically.
  - d. All of the above are correct.
  
4. In Figure 2-14, which PLC input triggers the flashing timing relay?
  - a. I1
  - b. I4
  - c. I5
  - d. I6
  
5. In Figure 2-17, which conditions cause the program to reset?
  - a. False (make) I1
  - b. True (break) I6
  - c. True (make) T1
  - d. None of the above is correct.

# Unit Test

1. What is connected to the coil of the Interposing Relays?
  - a. Output signal
  - b. Incoming signal
  - c. Overload relay
  - d. None of the above is correct.
  
2. What is needed to one side of the contact of the Interposing Relays?
  - a. Supply voltage
  - b. Push buttons
  - c. Overload relay
  - d. None of the above is correct.
  
3. Which device needs an interposing relay for AC to DC bridging?
  - a. DC Power Supply, Model 3139
  - b. Switches, Model 3112
  - c. Overload Relay module, Model 3131
  - d. None of the above is correct.
  
4. Which device needs an interposing relay for DC to AC bridging?
  - a. DC Power Supply, Model 3139
  - b. Switches, Model 3112
  - c. Overload Relay module, Model 3131
  - d. None of the above is correct.
  
5. Which device delivers appropriate voltage for the Programmable Logic Controller, Model 3128?
  - a. DC Power Supply, Model 3139
  - b. Control Transformer, Model 3138
  - c. AC Power Supply, Model 3196
  - d. None of the above is correct.
  
6. Which device delivers appropriate voltage for the Brake Motor, Model 3176-A?
  - a. DC Power Supply, Model 3139
  - b. Control Transformer, Model 3138
  - c. AC Power Supply, Model 3196
  - d. None of the above is correct.



7. Which device delivers appropriate voltage for the Selector Switches, Model 3111?
  - a. DC Power Supply, Model 3139
  - b. Control Transformer, Model 3138
  - c. AC Power Supply, Model 3196
  - d. None of the above is correct.
  
8. Why are low AC and DC voltages widely used in control circuits?
  - a. Simplify circuits
  - b. Increase electrical power in control circuits
  - c. Make the working environment of the operator safer
  - d. None of the above is correct.
  
9. How is the tripped overload status used in the Figure 2-17 PLC program?
  - a. Digital input signal
  - b. Analog input signal
  - c. Output signal
  - d. None of the above is correct.
  
10. Why would the tripped overload signal be used to reset the PLC motor control program?
  - a. To suggest the operator to stop the motor manually.
  - b. To prevent the motor from restarting automatically.
  - c. Because the motor overload might not be readily apparent.
  - d. None of the above is correct.

## Equipment Utilization Chart

The following Lab-Volt equipment is required to perform the exercises in this manual.

EQUIPMENT		EXERCISE							
MODEL	DESCRIPTION	1-1	1-2	1-3	1-4	1-5	2-1	2-2	2-3
3103 (or 8110 or 8134)	Mobile Workstation	1	1	1	1	1	1	1	1
3110	Push Buttons		1						
3112	Switches	1	1	2	1	1	1	1	2
3114	Emergency Button						1	1	1
3115	Pilot Lights		1						
3115-A	Pilot Lights	1	1	1	1	1	1		1
3119	Dual Contactors								1
3125	Lockout Module	1	1	1	1	1	1	1	1
3127	Contactor						1	1	
3128	Programmable Logic Controller	1	1	1	1	1	1	1	1
3129	Interposing Relays						1	1	1
3130	Control Relay		1						
3131	Overload Relay						1	1	1
3138	Control Transformer	1	1	1	1	1	1	1	1
3139	DC Power Supply	1	1	1	1	1	1	1	1
3147 (or 9126)	Inertia Wheel							1	1
3176-A (or 3176-B)	Brake Motor						1	1	1
3196 (or 8821)	AC Power Supply	1	1	1	1	1	1	1	1
8951	Connection Leads	1	1	1	1	1	1	1	1
8951-E	Connection Leads	1	1	1	1	1	1	1	1
N/A	Voltmeter <sup>(1)</sup>	1	1	1	1	1	1	1	1
<sup>(1)</sup> The Lab-Volt multimeter model 70-38707 can be used in all exercises requiring a voltmeter, a clamp-on ammeter, or an ohmmeter.									



## Diagram Symbols

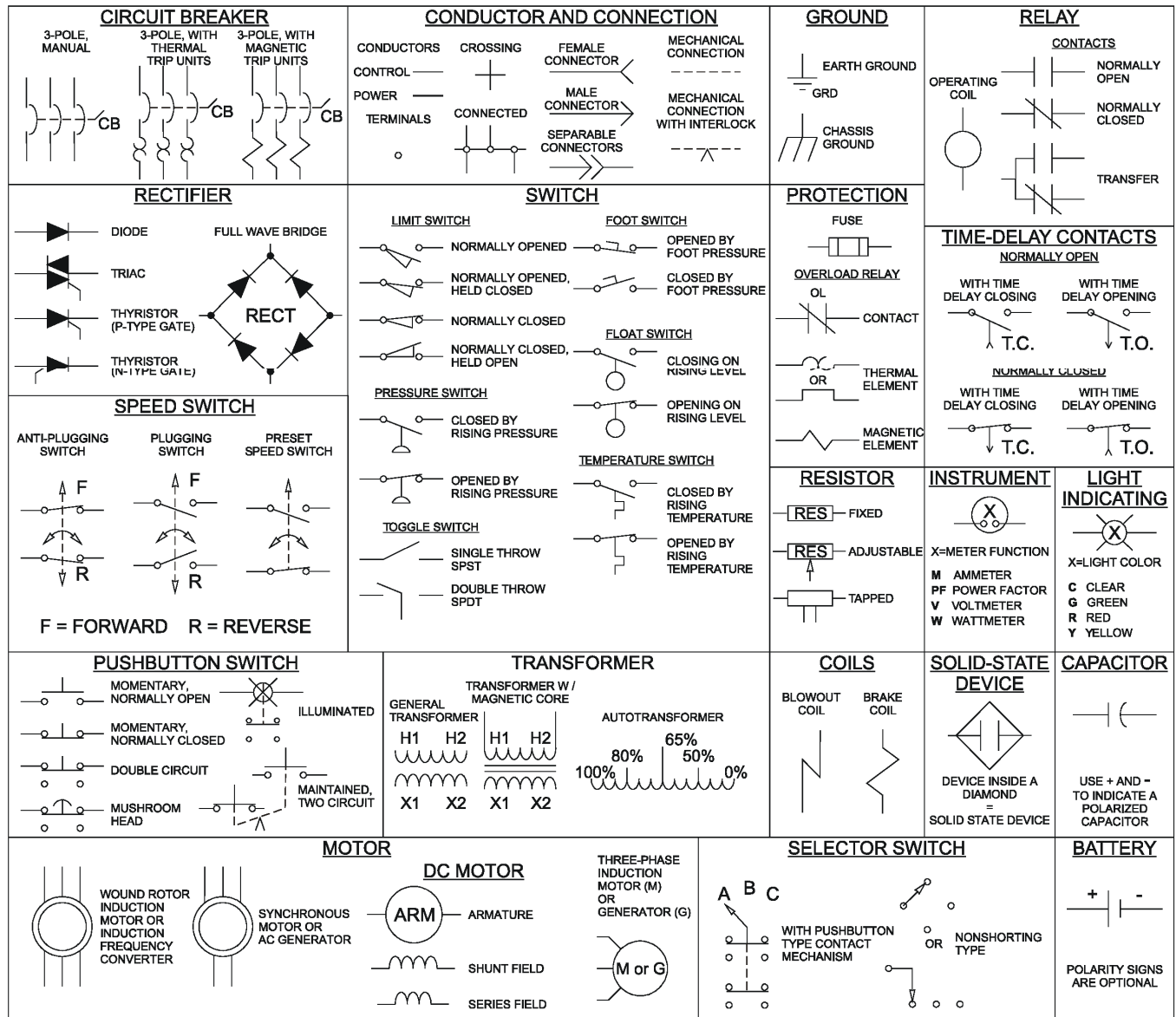


Figure B-1. NEMA symbols.

FUNCTION OR DEVICE	DESIGNATION	FUNCTION OR DEVICE	DESIGNATION
Accelerating	A	Overload	OL
Ammeter	AM	Overvoltage	OV
Braking	B	Plugging or Potentiometer	P
Capacitor, Capacitance	C or CAP	Power Factor Meter	PFM
Circuit Breaker	CB	Pressure Switch	PS
Closing Coil	CC	Push Button	PB
Control Relay	CR	Reactor, Reactance	X
Current Transformer	CT	Rectifier	REC
Demand Meter	DM	Resistor, Resistance	R or RES
Diode	D	Reverse	R or REV
Disconnect Switch	DS or DISC	Rheostat	RH
Dynamic Braking	DB	Selector Switch	SS
Field Accelerating	FA	Silicon Controlled Rectifier	SCR
Field Contactor	FC	Solenoid Valve	SV
Field Decelerating	FD	Squirrel Cage	SC
Field-Loss	FL	Starting Contactor	S
Forward	F or FWD	Suppressor	SU
Frequency Meter	FM	Tachometer Generator	TACH
Fuse	FU	Terminal Block or Board	TB
Ground Protective	GP	Time-Delay Closing Contact	TC or TDC
Holding Coil	HC	Time-Delay Opening Contact	TO or TDO
Hoist	H	Time Relay	TR
Jog	J	Transformer	T
Latch Coil	LC	Transistor	Q
Limit Switch	LS	Trip Coil	TC
Lower	L	Unlatch Coil	ULC
Main Contactor	M	Undervoltage	UV
Master Control Relay	MCR	Voltmeter	VM
Master Switch	MS	Watt-hour Meter	WHM
Overcurrent	OC	Wattmeter	WM

Figure B-2. Device designations.


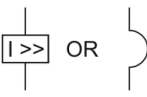
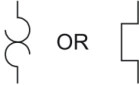
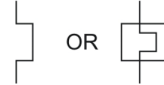






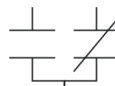


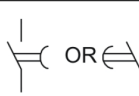


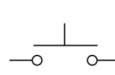

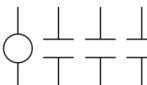
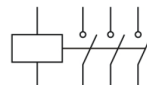
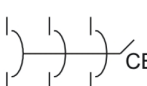

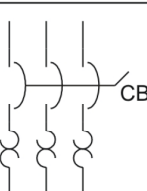
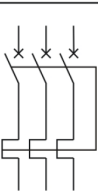
	NEMA	IEC
MAGNETIC OVERLOAD ELEMENT (SHORT-CIRCUIT)		
THERMAL OVERLOAD ELEMENT		
RELAY COIL		
NORMALLY OPEN CONTACT		
NORMALLY CLOSED CONTACT		
TRANSFER CONTACTS		
NORMALLY OPEN CONTACT DELAYED WHEN CLOSING		
NORMALLY OPEN CONTACT (LIMIT SWITCH)		
NORMALLY OPEN PUSHBUTTON CONTACT		
CONTACTOR		
THREE-POLE SWITCH-DISCONNECTOR		
THREE-POLE CIRCUIT-BREAKER WITH THERMAL OVERLOAD RELEASES		

Figure B-3. Comparison of NEMA and IEC symbols.



## PLC and Software Reference

### EASY500 PLC



Figure C-1. Programmable Logic Controller module, Model 3128.

#### Purpose of the buttons

- DEL: Delete object in circuit diagram.
- ALT: Special function in circuit diagram, status display.
- ESC: Previous menu level, cancel.
- OK: Next menu level, save your entry.
- Cursor buttons: Move cursor, select menu items, change values.

#### Programmable Logic Controller module's main features

- Power supply: 24 V dc
- Digital inputs: I1 to I8



- Analog inputs: I7 and I8
- Digital 0 signal: < 5 V dc (I1 to I8)
- Digital 1 signal: > 8 V dc (I7 and I8); > 15 V dc (I1 to I6)
- Counters: C1 to C16
- Analog value comparator: A1 to A16
- Text display function relays: D1 to D16
- Markers: M1 to M16; N1 to N16
- Operating hours counters: O1 to O4
- Cursor buttons: P1 to P4
- Conditional jump: :1 to :8
- Time function relays: T1 to T16
- Master reset: Z1: Q outputs reset; Z2: M and N markers reset; Z3: Q, M, and N reset
- Output contacts: Q1 to Q4

### **EASY-SOFT SOFTWARE**

Your Programmable Logic Controller module, Model 3128, is provided with the Easy-Soft software from Moeller. This software enables developing, storing, testing, and managing ladder circuit diagrams on a personal computer (PC). The data transfer between the PLC and the PC is done through a special serial cable, called Easy-PC-CAB.

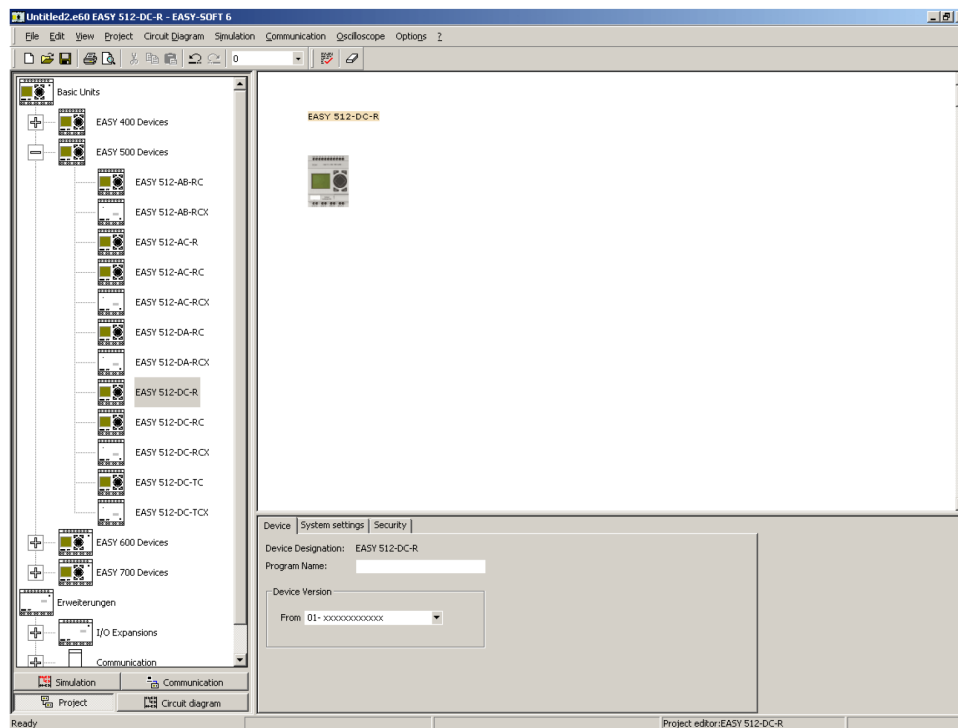
Although you can program the PLC directly on the device, it is often more convenient to enter the ladder circuit on a PC. Selection menus and the use of a mouse greatly simplify connection of the elements. Additionally, by developing a circuit diagram on a PC, you can work on different versions without having to stop the PLC, thereby reducing production down time. It is also possible to test circuits directly on the PC by using the offline simulation mode. Therefore, you ensure that the circuit functions as intended before connecting the hardware.

### **EASY-SOFT SYSTEM REQUIREMENTS**

To use the Easy-Soft software, you will need a personal computer running under Windows NT, 2000, or XP.

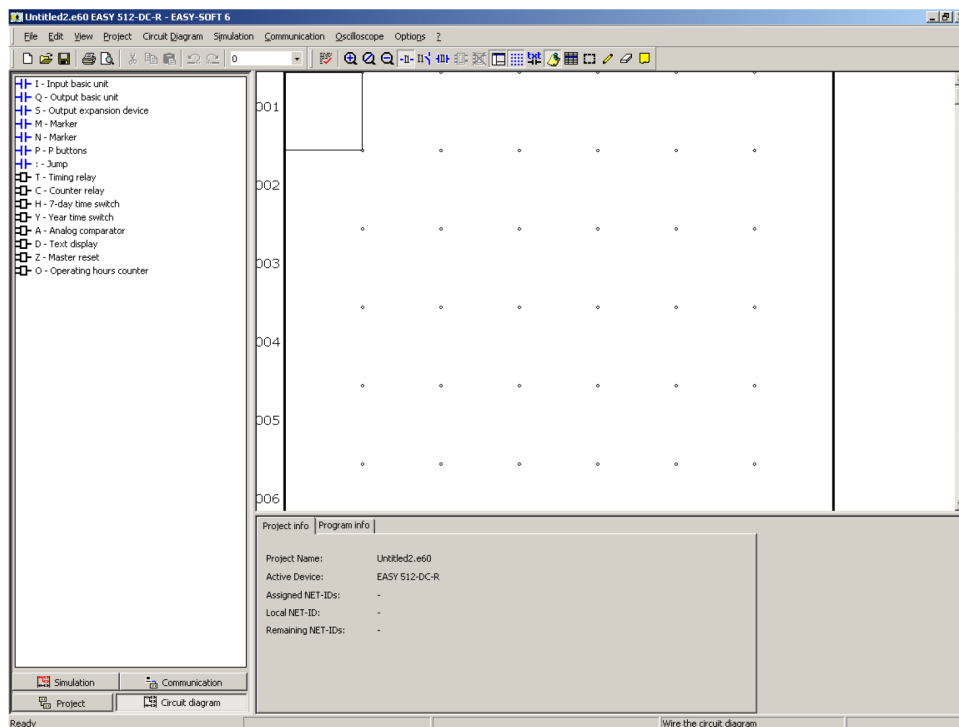
### PROCEDURE TO ENTER AND TEST A PROGRAM VIA EASY-SOFT

1. Start the Easy-Soft program on your PC. On the left menu, choose the EASY 512-DC-R icon and drag it to the empty space on the right. A small window will appear. Click OK for a device version starting with 01-. You may now assign a program name in the dedicated box, located at the bottom of the screen. Figure C-2 shows how the project window looks like.



**Figure C-2. Starting a project with Easy-Soft.**

At the bottom left of the screen, you will find buttons that give access to the different windows of the program (Simulation, Communication, Project, and Circuit diagram). Click on the Circuit diagram button. You are now ready to enter your program. The Circuit diagram window is displayed in Figure C-3.



**Figure C-3. Circuit diagram window.**

2. Enter your program. To add an item, drag the appropriate icon from the left menu to the ladder diagram on the right. Parameters of the items can be modified on the bottom right of the screen. By clicking on the right button of your mouse, you have access to the Eraser and Pencil tools that enable editing the lines of the circuit.

**Note:** Easy-Soft offers you relevant information while you work.  
Just press F1 any time you need some help.

## PROGRAM SIMULATION

3. Once the program is entered, switch to the Simulation window to test your circuit. Start the simulation by clicking on the Start option in the Simulation menu, at the top of the window, as Figure C-4 shows.

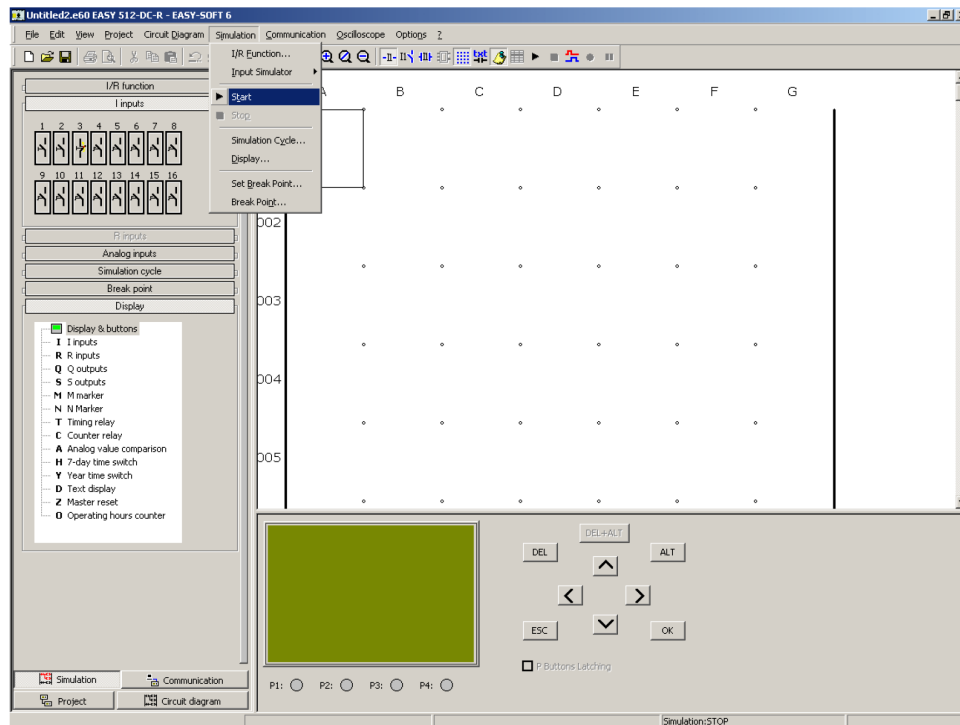


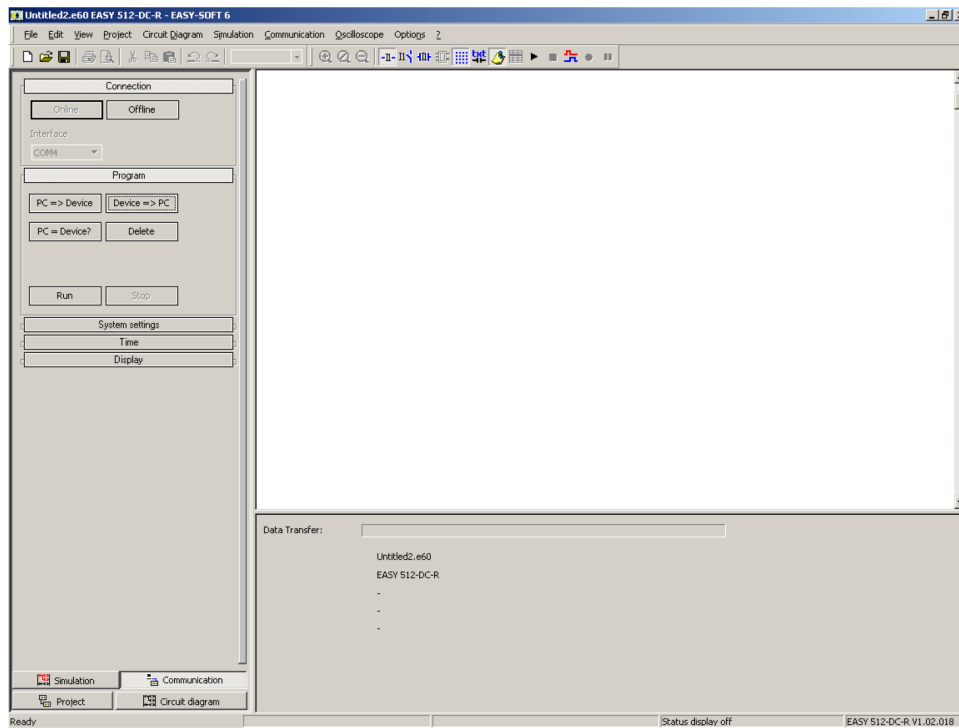
Figure C-4. Starting the simulation.

From now on, the diagram lines and contacts will change color, indicating what contacts are energized or not. To simulate the activation of an input, click on the button entitled "I inputs" on the left, before clicking on input number icons. To visualize the effect of the program on the PLC, click first on the "Display" button, before choosing "Display & buttons". You will then see a simulated PLC status window that will react to stimulations.

## TRANSFERRING DATA AND OPERATION

4. Make sure that the serial cable is installed correctly between the computer and the PLC. Turn on the DC Power Supply and check if the PLC is turned on. Set the PLC to the STOP mode and return to the status window.

Access the communication window of the Easy-soft program. Press the Connection button and choose the Online function to make the PC connect to the PLC. Press the Program button and choose the PC=>Device option. The program data will transfer from the PC to the PLC, as you can see in Figure C-5.



**Figure C-5.** Transferring PC data to the PLC.

**Note:** On the Easy-soft Communication screen, you can change the PLC mode by pressing the RUN or STOP button, while the connection between the two devices is on.

## Basic Setup and Lockout/Tagout Procedures Answers to Unit Test Questions

This appendix is divided into three sections:

- *Basic Setup procedure*, explains the basic operations that must be performed at the beginning of the exercise procedures.
- *Lockout/Tagout procedure (de-energizing procedure)*, describes the lockout/tagout procedure used to de-energize the Industrial Controls Training System before setting up a circuit.
- *Energizing procedure*, gives details on how to end a lockout/tagout procedure and energize the Industrial Controls Training System.

### I. Basic Setup procedure

This procedure is recommended at the beginning of every experiment. It insures that the system is safe prior to cabling specific circuits.

- ☐ 1. Make sure that the power switch of the power supply is set to the off position.

**Note:** *The power supply should already be installed in the workstation.*

- ☐ 2. Install the Lockout Module in the workstation.
- ☐ 3. Turn off the Lockout Module.
- ☐ 4. Connect the Lockout Module leads to the power supply terminals, respecting the phase sequence.

### II. Lockout/Tagout procedure (de-energizing procedure)

- ☐ 1. Turn off the Lockout Module.
- ☐ 2. Install the lockout hasp and the student padlocks and tags on the Lockout Module. Ask the instructor to install the lab padlock and tag as well.

- ☐ 3. Check that the Lockout Module switch cannot be opened. With a voltmeter, verify that no voltage is present between the Lockout Module output terminals to confirm that the circuit is de-energized. You may now set up your circuit.

### III. Energizing procedure

- ☐ 1. Connect the green chassis terminals (on the modules) to the earth (ground) terminal of the Lockout Module.
- ☐ 2. Make sure the security guard is installed if you are using a motor.
- ☐ 3. Identify the push buttons, selector switches, and pilot lights with magnetic labels in accordance with the circuit schematic diagram.
- ☐ 4. Once the connections are made, ask for the instructor to check the circuit. When the circuit is correctly wired, notify all the people working around the workstation that the system will be energized.
- ☐ 5. Remove the lockout hasp, padlocks and tags.

**Note:** If you are using the Power Supply, Model 8821, make sure that the voltage control knob is set to 0%.

AC and DC voltages (fixed or variable) are available on the Power Supply, Model 8821. For all exercises requiring AC voltage, use the AC variable output (terminals 4, 5 and 6).

- ☐ 6. Turn on the power supply and Lockout Module, and return to your exercise.

**Note:** If you are using the Power Supply, Model 8821, set the voltage control knob to 100%.

## Boolean Algebra and Digital Logic

Boolean algebra is a mathematical solution applied to logic problems. It is based on problems which have only two outcomes, such as true or false, on or off, 0 or 1, and opened or closed.

There are three basic operators in Boolean algebra. They are logical NOT, logical AND and logical OR.

The logical NOT operator inverts a function or variable. The inverse of 1 is 0 and the inverse of 0 is 1. The logical NOT is indicated by a bar above the function or variable.

The logical AND operator is performed on two or more variables such as A or B. The result of ANDing two or more variables is a logical 1 if every variable is a logical 1. The result is a logical 0 if any variable is a logical 0. The logical AND is indicated by a dot between the variables, such as:

$$A \cdot B$$

The logical OR operator is performed on two or more variables, such as A and B. The result of ORing two or more variables is a logical 1 if any variable is a logical 1. The result is a logical 0 if every variable is a logical 0. The logical OR is indicated by a plus sign between the variables, such as:

$$A + B$$

A Boolean statement is a shorthand method of describing a logic statement using Boolean operators. The statement  $A \cdot B + C = Y$  is read A AND B, OR C equals Y. This means that the variable Y will be a logical 1 if both A and B are logical 1's, or if C is a logical 1.

In a Boolean statement, there is an order of precedence for the operators. This is listed in Table E-1.

1. Statements within brackets and under bars are performed first. A bar over two or more variables is considered the same as placing the variables within brackets. In this case, the statement under the bar is performed first, and then inverted.
2. Perform all NOT (invert) function on single variables.
3. Perform all AND functions.
4. Perform all OR functions.

**Table E-1. Order of Precedence in a Boolean Statement.**

Postulates are the basic assumptions from which the properties, rules, and theorems of a system can be deduced.



The postulates that are the basis for Boolean algebra are listed in Table E-2.

1. $X = 0$ or $X = 1$	5. $1 \cdot 1 = 1$
2. $0 \cdot 0 = 0$	6. $1 \cdot 0 = 0, 0 \cdot 1 = 0$
3. $1 + 1 = 1$	7. $1 + 0 = 1, 0 + 1 = 1$
4. $0 + 0 = 0$	

**Table E-2. Postulates that are the basis for the Boolean algebra.**

The theorems of Boolean algebra are derived from these postulates. Table E-3 lists the theorems of Boolean algebra.

THEOREM 1.	Commutative Law	THEOREM 6.	Redundance Law
	(a) $A+B=B+A$		(a) $A+A \cdot B=A$
	(b) $A \cdot B=B \cdot A$		(b) $A \cdot (A+B)=A$
THEOREM 2.	Associative Law	THEOREM 7.	(a) $0+A=A$
	(a) $(A+B)+C=A+(B+C)$		(b) $1+A=1$
	(b) $(A \cdot B) \cdot C=A \cdot (B \cdot C)$		(c) $0 \cdot A=0$
THEOREM 3.	Distributive Law		(d) $1 \cdot A=A$
	(a) $A \cdot (B+C)=A \cdot B+A \cdot C$	THEOREM 8.	(a) $\bar{A}+A=1$
	(b) $A+(B \cdot C)=(A+B) \cdot (A+C)$		(b) $\bar{A} \cdot A=0$
THEOREM 4.	Identity Law	THEOREM 9.	(a) $A+\bar{A} \cdot B=A+B$
	(a) $A+A=A$		(b) $A \cdot (\bar{A}+B)=A \cdot B$
	(b) $A \cdot A=A$	THEOREM 10.	DeMorgan's Theorem
THEOREM 5.	Negation Law		(a) $\overline{A+B}=\bar{A} \cdot \bar{B}$
	(a) $(A)=\bar{A}$		(b) $\overline{\bar{A} \cdot B}=\bar{A}+B$
	(b) $(\bar{A})=A$		

**Table E-3. Boolean Theorems.**

Digital logic is a method of implementing Boolean statements into a control circuit or program. The Boolean operators (AND, OR, and NOT) are performed by logic gates. A logic gate receives input signals and transmits an output signal. The output signal will be a function of the input signal. Six common logic gates are: AND, OR, NOT, NAND, XOR, and XNOR.

The AND, OR, and NOT gates perform the same function as the AND, OR, and NOT operators in Boolean algebra. A NAND gate performs the inverse function of an AND gate. The NOR gate performs the inverse function of an OR gate. The XOR gate has two inputs; if one input or the other input, but not both, are logical 1s, then the output is a logical 1. The XNOR gate performs the inverse function of an XOR gate. The table of Figure E-1 lists the types of gates, gate symbols, and truth tables for each gate. The gate inputs are indicated as either A or B, and the gate outputs are indicated by Y.

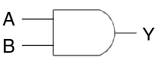

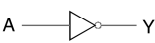


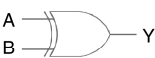

GATE	SYMBOL	TRUTH TABLE															
AND		<table><tr><th>A</th><th>B</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	A	B	Y	0	0	0	0	1	0	1	0	0	1	1	1
A	B	Y															
0	0	0															
0	1	0															
1	0	0															
1	1	1															
OR		<table><tr><th>A</th><th>B</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	A	B	Y	0	0	0	0	1	1	1	0	1	1	1	1
A	B	Y															
0	0	0															
0	1	1															
1	0	1															
1	1	1															
NOT		<table><tr><th>A</th><th>Y</th></tr><tr><td>0</td><td>1</td></tr><tr><td>1</td><td>0</td></tr></table>	A	Y	0	1	1	0									
A	Y																
0	1																
1	0																
NOR		<table><tr><th>A</th><th>B</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	A	B	Y	0	0	1	0	1	0	1	0	0	1	1	0
A	B	Y															
0	0	1															
0	1	0															
1	0	0															
1	1	0															
NAND		<table><tr><th>A</th><th>B</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	A	B	Y	0	0	1	0	1	1	1	0	1	1	1	0
A	B	Y															
0	0	1															
0	1	1															
1	0	1															
1	1	0															
XOR		<table><tr><th>A</th><th>B</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	A	B	Y	0	0	0	0	1	1	1	0	1	1	1	0
A	B	Y															
0	0	0															
0	1	1															
1	0	1															
1	1	0															
XNOR		<table><tr><th>A</th><th>B</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	A	B	Y	0	0	1	0	1	0	1	0	0	1	1	1
A	B	Y															
0	0	1															
0	1	0															
1	0	0															
1	1	1															

Figure E-1. Logic Gates.

Programmable Controllers often use Boolean operators or logic gate functions as program instructions. These instructions are often used in combination with programmed NO and NC contacts.

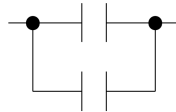
The AND instruction is used to connect programmed contacts or ladder program sections in series. The OR instruction is used to connect programmed contacts or ladder program sections in parallel. The NOT instruction changes a NO programmed contact to a NC programmed contact.

Figure E-2 shows two contacts ANDed together.



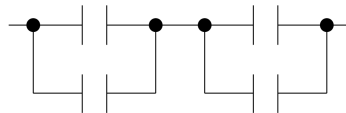
**Figure E-2. Two ANDed Contacts.**

Figure E-3 shows two contacts ORed together.



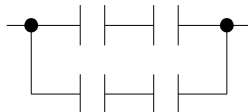
**Figure E-3. Two ORed Contacts.**

Figure E-4 shows two sets of ORed contacts ANDed together.



**Figure E-4. Two ANDed Ladder Program Sections.**

Figure E-5 shows two sets of ANDed contacts ORed together.



**Figure E-5. Two ORed Ladder Program Sections.**

# Bibliography

Herman, S.L. *Industrial Motor Control, Fifth Edition*. Clifton Park, NY: Thomson Delmar Learning, 2005, ISBN 1401838022.

Industrial Training Zone. *PLC Fundamentals*. Farmingdale, NJ: Lab-Volt Systems 2006.

International Electrotechnical Commission. *Graphical Symbols for Diagrams*. IEC 60617.

National Center for Construction Education and Research. *Electrical Level 3 Trainee Guide*. Upper Saddle River, NJ: Pearson/Prentice Hall, 2002, ISBN 0130472239.

National Electrical Manufacturers Association. *Industrial Control and Systems: Diagrams, Device Designations, and Symbols*. ICS 19-2002.

National Electrical Manufacturers Association. *NEMA and IEC Devices for Motor Services - A Guide for Understanding the Differences*. ICS 2.4-2003.

Rockis, G., and Glen Mazur. *Electrical Motor Controls, Second Edition*. Homewood, IL: American Technical Publishers Inc., 2001, ISBN 0826916759.

Wildi, T. *Electrical Machines, Drives and Power Systems, Sixth Edition*. Englewood Cliffs, NJ: Prentice Hall, 2005, ISBN 0131776916.

