Monitoring and Control of a Process by SCADA via Grafcet and Ladder Diagram Programming

By

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FINAL PROJECT REPORT

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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Ahmad Faiz bin Fauzi

ABSTRACT

This report discusses the development of a Supervisory Control and Data Acquisition (SCADA) system for the monitoring and control of a process using Programmable Logic Controller (PLC) via Grafcet and Ladder Diagram (LD) programming. The report explains the background and several methods to program a PLC. When dealing with a PLC, Grafcet is becoming the preferable method to work with because of its easiness and the clear flow of program. In this work, the Tidal Gate Control System (TGCS) is selected as a case study to investigate the advantages and disadvantages of Grafcet over LD. A literature review to track the achievements of researchers in using Grafcet and about Grafcet have been conducted. Procedure and tools required to develop TGCS are elucidated. Results on the implementation of the project are discussed. Programming the PLC to implement the monitoring and control of TGCS via Grafcet is more convenient compared to programming via LD. The recommendations on the future works of this project are also discussed.

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First of all, my greatest thanks to Allah S.W.T for His bless for giving me a chance to finish the project.

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LIST OF ABBREVIATIONS

SCADA	Supervisory Control and Data Acquisition
PLC	Programmable Logic Controller
Grafcet	Graphe de Commande Etape Transition
LD	Ladder Diagram
TGCS	Tidal Gate Control System
FYP	Final Year Project
IEC	International Electrotechnical Commission
SFC	Sequential Function Charts
LD	Ladder Diagram
FBD	Function Block Diagram
ST	Structured Text
IL	Instruction List
I/Os	Inputs-Outputs
VDINs	Virtual Digital Inputs
HRs	Holding Relays
AIN	Analog Input
LT	Level Transmitter

CHAPTER 1
INTRODUCTION

1.1 Background

More than two decades ago, a wide range of different programming techniques has been used to write programs for industrial control applications and for Programmable Logic Controllers (PLCs). Control applications have been developed in BASIC, FORTH, C, Structured English, Instruction List and numerous other languages. This contributed difficulties for people involved with such systems i.e. the technicians, maintenance personnel, system designers to plant managers to learn and to be trained in the different control languages. In order to solve the problem IEC 61131-3 standard was published in March 1993 to provide standard that defined the way control systems such as PLCs could be programmed [1].

The IEC 61131-3 standard currently defines five programming languages for PLCs:

i. Sequential function chart (SFC)
ii. Ladder diagram (LD)
iii. Function block diagram (FBD)
iv. Structured text (ST)
v. Instruction list (IL)

SFC or also known as Grafcet is a graphical language for depicting sequential behavior of a control system. LD is also a graphical language that is based on the relay ladder logic. This particular method to program PLCs is commonly in the industries [2]. FBD is graphical language as well. It is used for depicting signal and data flows through function blocks.

ST is a high level textual language that encourages structured programming. It has a syntax that strongly resembles PASCAL and supports a wide range of standard functions and operators. IL is a low level language that is somewhat similar to assembly language.

Different types of PLC programming language require different approaches and programming styles. Each of the programming methods has their own advantages and disadvantages. No matter the method of programming a PLC is chose, it shares the same objective that is to program the PLC to perform certain specific tasks.

1.2 Problem Statement

PLC is used to control automated systems such as manufacturing cells and plant process. The program within the PLC determines the way the inputs control the outputs and there are many methods of programming a PLC to achieve this outcome.

Since the introduction of PLC as a controller in the automobile industry in the late 60s, PLCs are becoming more powerful with more functions and more extensively used nowadays. There are several processes that require the system to perform multi-tasking operation. For example, the distributed control, sequential control, and factory control system integration all require PLC that is capable of performing complex control functions, production monitoring, data collection, alarm functions, and system diagnostics all at the same time [3].Thus programming techniques in LD such as timer, counter, comparison, data movement and more additional functions are required in the design. The programming tends to become lengthy, complex and difficult to follow.

In order to give the PLC a 'sense of history' [3], a method called latching effect need to be implemented in the LD. One issue with using latch is that the LD needs to unlatch the latching effect. During production downtime situations, a great amount of time is usually required to track and trace the program latch and unlatch sequence before the system fault can be traced and corrected.

To overcome the LD limitations, Grafcet has been proposed [2]

1.3 Objectives and Scope of Study

The main objectives of the project are as follows:

- To understand the architecture and design of Grafcet programming
- To construct a workable process controlled via Grafcet and LD programming
- To study the advantages and disadvantages of Grafcet over LD
- To monitor and control the workable process via Supervisory Control and Data Acquisition (SCADA)

This project focuses on Grafcet and LD programming. In order to understand the advantages or disadvantages of Grafcet over LD, a workable process, Tidal Gate Control System (TGCS) has been developed. TGCS design has been developed both via Grafcet and LD programming.

1.4 Tidal Gate Control System

Figure 1.1 shows an overview of TGCS that has been selected to be in this study. Detail descriptions of the system are provided in section 1.4.1

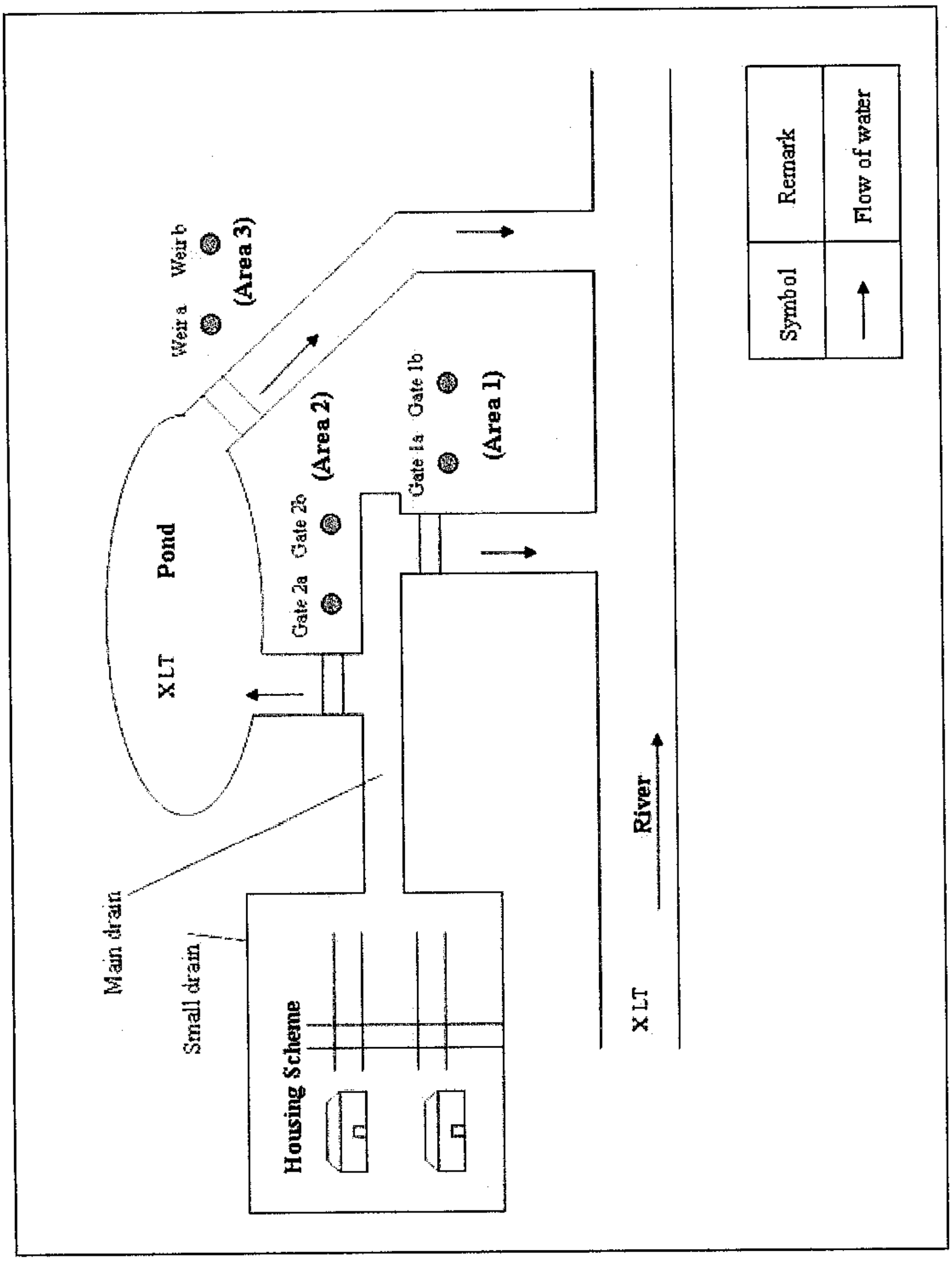


Figure 1.1: Tidal Gate Control System overview

1.4.1 Tidal Gate Control System Design Descriptions

TGCS can be described as open channel hydraulics. Open channels hydraulics is a type of fluid flow in which the flowing fluid will form a free surface and is driven by gravity [3]. In this study, the main areas to be considered are the housing scheme, pond and river. The highest topography is the housing scheme, followed by pond and river. From the effect of gravitational force, the water will tend to flow from the housing scheme to the pond and river, and on the same token the water from pond will tend to flow to the river. There are small drains in the housing scheme area which are connected to a main drain. This main drain is connected to river and pond. There is also a drain connected between the river and pond. TGCS has been designed to provide the following gates and weirs operation:

i. Automatic Control Mode
ii. Manual Control Mode
iii. SCADA Control Mode
iv. Preloads Condition

1.4.1.1 Automatic Control Mode

In automatic control mode, the system is able to detect the high water level at the river and pond automatically by utilizing river level transmitter (LT) and pond LT. Gates and weirs are open and closed according to the level of the river and pond. A river LT and a pond LT are located at the river and pond respectively to monitor the water level of these areas. Gate 1a and Gate 1b are placed to control the water flow from the housing scheme to the river. Gate 1a and Gate 1b are designed not to open simultaneously. Gate 2a and Gate 2b are placed to control the water flow from the housing scheme to the pond, and Weir a and Weir b are placed to control the water flow from the pond to the river. Gate 2a and Gate 2b, and Weir a and Weir b are also designed not to open simultaneously. Only one gate with the lowest run-hour at Area 1 and one gate with the lowest run-hour at Area 2 and one weir with the lowest run-hour at Area 3 should be open at a time. If the run-hour of gates and weirs at Area 1, Area 2 and Area 3 are happened to be the same, Gate 1a, Gate 2a and Weir a is selected to be opened. This particular gates and weirs control is called Gates Sequence and Weirs Sequence, which is discussed in details in section 4.4.4 at page 36.

The initial condition of gates at Area 1, is Gate 1a is open Gate 1b is closed. The initial condition of gates at Area 2 both are closed and both weirs at Area 3 are closed as well. The system initiates when rain starts to fall. The excessive water from small drains will flow into the main drain. Since Gate 1a is open and gates at Area 2 are closed, the water will flow to the river.

If rain continues and the river reaches its limit, gates at Area 1 will be closed (in 10-second delay) and one gate at Area 2 with the lowest run-hour will be opened. This will channel the water to the pond. The pond will act as the alternative place to keep the excessive water from the housing scheme. Gates at Area 1 delay-to-close is discussed in fine points in section 4.4.5 at page 40.

If rain continues with heavy pours and caused the river and the pond to reach their limit, both gates at Area 1 will be opened while gates at Area 2 and weirs are closed. This is the worst condition where TGCS can no longer function as a flood mitigation system for the housing scheme.

Once the level of river is safe, one gate at Area 1 with the lowest run-hour will be opened and gates at Area 2 will be closed.

If somehow the pond reaches its limit, one weir with the lowest run-hour will be opened and gate at Area 1 continues its operation. This will allow excessive water from the pond to flow to the river. The weir will be closed when the level of the pond is at its normal level.

The flowchart of the automatic control mode is shown in Flowchart 1 in Appendix A.

1.4.1.2 Manual Control Mode

In manual control mode, operators are able to operate the gates and weirs manually by pressing the open or the close switch at the panel. The manual control mode has a higher priority than the automatic control mode and the SCADA control mode for security purposes especially during maintenance.

The flowchart of the manual control mode is shown in Flowchart 2 in Appendix A.

1.4.1.3 SCADA Control Mode

SCADA control mode allows only the authorized operators to control the gates and weirs remotely with password protected. Control buttons to open and close gates and weir are provided in the TGCS picture mimic. SCADA control mode has the higher priority than the automatic control mode for security and remote control purposes.

The flowchart of the SCADA control mode is shown in Flowchart 3 in Appendix A.

1.4.1.4 Preloads Condition

Preloads condition is included in the TGCS design to offer safety measures for the system. TGCS is able to check the healthiness of the equipments which include power trip, motor trip and sensors error. Any of these measures occurred, the TGCS operation is designed to stop to prevent any further damage to the system or to the equipments.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Introduction

Grafcet is an acronym of the French word (Graphe de Commande Etape Transition). It is a graphical language that was proposed in France in 1977. In 1988, Grafcet was accepted by the International Electrotechnical Commission (IEC) as an international standard named IEC 848. In this standard, Grafcet is referred to under the name Sequential Function Charts (SFC) [4]. Five years later, Grafcet or SFC or IEC 848, was acknowledged to be one of the five languages defined by the IEC 61131-3 standard.

2.2 Grafcet

The advantages of graphical programming languages are their simplicity and declarativeness [4]. SFC or Grafcet can explicitly represent the sequential flow in the control logic. This will make Grafcet easier to program and understand by the operators. Grafcet treats timer, counter, latching effect and other techniques in LD in an easier way. Thus a complicated process is easier to develop via Grafcet. Today, Grafcet/SFC is well accepted in industry compare to other methods much thanks to its clear graphical interface [4]. Grafcet also offers an inherently stable structure, shorter scan time and easy to troubleshoot [5]

2.2.1 Grafcet Blocks

Figure 2.1 shows the blocks that build up a Grafcet. Grafcet is built up by steps, drawn as squares, and transitions that are represented as bars. The initial step is represented as a double square [4].

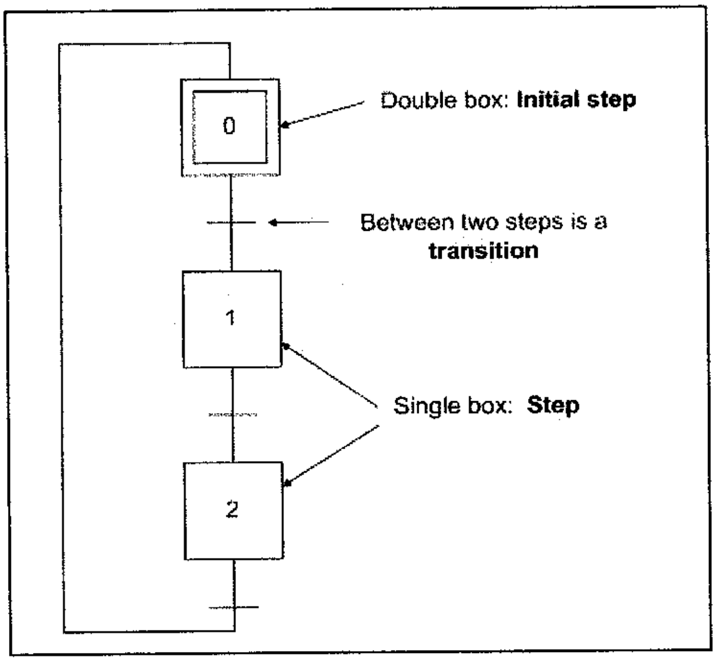


Figure 2.1: Grafcet building blocks

Initial step is the step that should be activated first when the system is started. Transitions are used to connect steps. A transition enables the next step to become active and the preceding step inactive. It is the condition state or the input of the process, which can be the sensors, switches, timers, counters and etc. A step can be active or inactive. It describes the situation of a process that it is representing. It can be representing the output of a certain process.

To cater for more complex control requirements, two branching techniques are envisaged which are selective branching and parallel branching [5]. Selective branching and parallel branching are shown in Figure 2.2 and Figure 2.3 respectively.

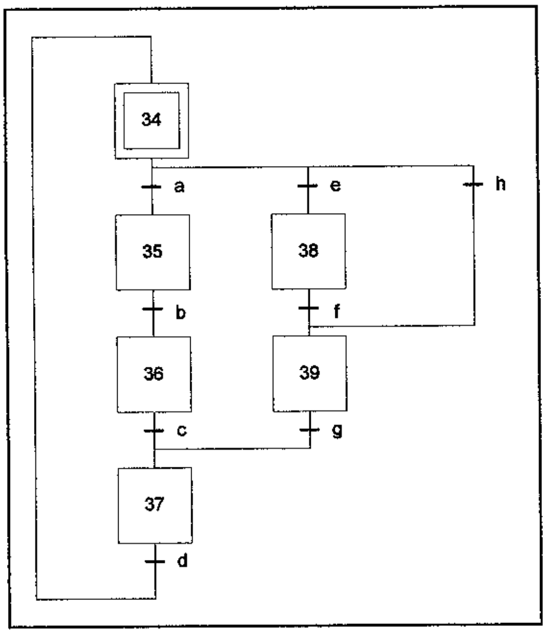


Figure 2.2: Selective branching in Grafcet

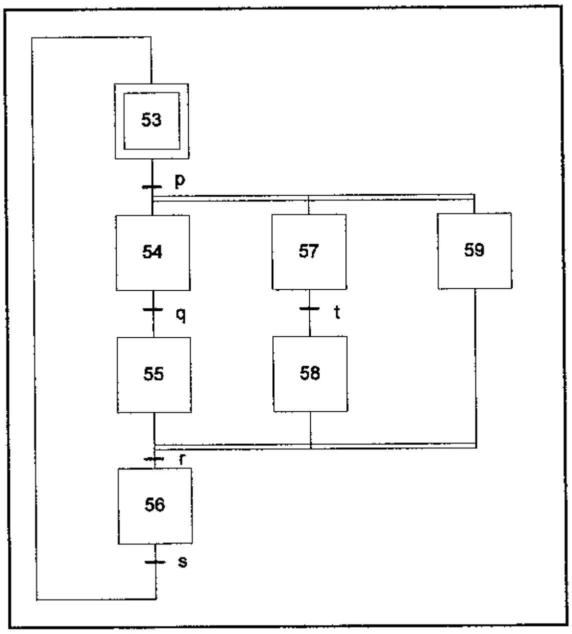


Figure 2.3: Parallel branching in Grafcet

Selective branching allows a choice of sequences to be executed in the Grafcet. Refer to Figure 2.2, there are 3 choices of sequence available which are (34 35 36 37) , (34 38 39 37) and (34 39 37). Condition of transition 'a', 'e' and 'h' must be exclusive which means they cannot active at the same time. For step 37 to active, either 'c' or 'g' must be true or high.

Parallel Branching allows two or more sequences to proceed simultaneously. Refer to Figure 2.3, if transition 'p' is true, step 54, step 57 and step 59 are activated at the same time. In order to move to transition 'r', step 55, step 58 and step 59 must be true or high.

2.3 The Related Technology on Flood Mitigation - Open Channel Hydraulics

Open channel hydraulics is the study of the physics of fluid flow in conveyances in which the flowing fluid forms a free surface and is driven by gravity. Natural open channels include brooks streams, rivers, and estuaries. Artificial open channels are exemplified by storm sewers, sanitary sewers, and culverts flowing partly full, as well as drainage ditches, irrigation canals, aqueducts, and flood diversion channels. Applications of open channel hydraulics range from the design of artificial channels for beneficial purposes such as irrigation, drainage, water supply, and wastewater conveyance to the analysis of flooding in natural waterways to delineate floodplains and assess flood damages for a flood of specified frequency. Principles of open channel hydraulics also are utilized to describe the transport and fate of environmental contaminants, including those carried by sediments in motion, as well as to predict flood surges caused by dam breaks or hurricanes [6].

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

The tasks undertaken during the implementation of this work is summarized as follows:

Task 1: Conduct research on Grafcet to gain some understanding.

Task 2: Study the architecture of Grafcet.

Task 3: Study on how to use Automgen7 to develop Grafcet.

Task 4: Develop Grafcet and LD program for TGCS.

Task 5: Integrate and download the developed Grafcet and LD program into PLC.

Task 6: Develop communication between SCADA and PLC.

Task 7: Monitoring and control of TGCS via SCADA.

3.2 Tools Required

The tools required for the project consist of 4 software and hardware. The software and hardware are explained in the next section.

3.2.1 Automgen7.101 Software

Automgen7 is utilized largely in the implementation of TGCS to develop Grafcet programming. Having the Omron Post Processor which is included in the Automgen7, Grafcet program that has been developed can be downloaded to the Omron PLC. Omron Post Processor will act just like a driver to support the difference of protocol used by Automgen7 and Omron PLC. Automgen7 application is not limited for the development purpose of Grafcet only. Automgen7 is equipped with a feature which is called IRIS where Automgen7 can serve as an OPC Client.

3.2.2 Cx-Programmer Software

Cx-Programmer is the software to develop the LD. This software is manufactured by Omron and LD can be downloaded easily to any type of Omron PLCs.

3.2.3 OPC Server Software

Two OPC Servers software are identified that are suitable to be utilized for Omron PLC: INGEAR Omron OPC Server and KEPware Enhanced OPC/DDE Server. Both OPC Servers can support Omron Sysmac Protocol and the PLC data are possible for Adroit to acknowledge and manipulate. However, KEPware Enhanced OPC/DDE Server is preferred to work with due to its user-friendly interface. The software is equipped with OPC Quick Client which enables the users to monitor the current value of the points that have assigned conveniently.

3.2.4 OPC Client, SCADA Software

Adroit6 will be utilized as the OPC Client for the project instead of Automgen7 itself. This is due to the fact that Adroit6 offers a better graphical display for TGCS compared to IRIS. Adroit6 will receive information from KEPware Enhanced OPC/DDE Server and represent the information into graphical and more understandable objects. Adroit6 will perform the monitoring of the events occurred and able to control the Omron PLC digital outputs remotely.

3.2.5 Omron PLC Hardware

Omron PLCs which are available at the laboratory are the CQM1H CPU51, C200HE CPU42 and etc. Omron PLC that is utilized in this work is CQM1H CPU41 type. This is because Automgen7 Omron Post Processor can support the communication for this particular type of Omron PLC only. Communications between the computer and CQM1H are established by having RS232 serial port as the communication medium.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Grafcet programming via Automgen7

Automgen7 will be the platform to develop Grafcet for TGCS. The following sections discussed about syntaxes and method on how to achieve certain programming techniques to program the Omron CQM1H PLC.

4.1.1 I/Os syntax and Symbols

Basically, Automgen7 has its own syntax on how to give instruction commands to Grafcet. Syntax for step that is placed inside the action triangle is %Q and the syntax for transition is %i. The action triangle is shown in Figure 4.1. There is alternative method to utilize these syntaxes by placing them in Symbols instead of inside the Grafcet action triangle blocks.

Figure 4.1 and Figure 4.2 show Grafcet I/Os have been assigned with its I/Os default syntax and Grafcet I/Os have been assigned with its symbols respectively. Figure 4.3 shows the Symbols that has been created.

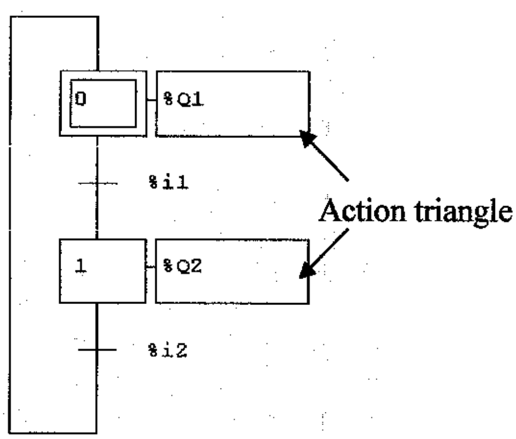


Figure 4.1: Grafcet with default I/Os syntax

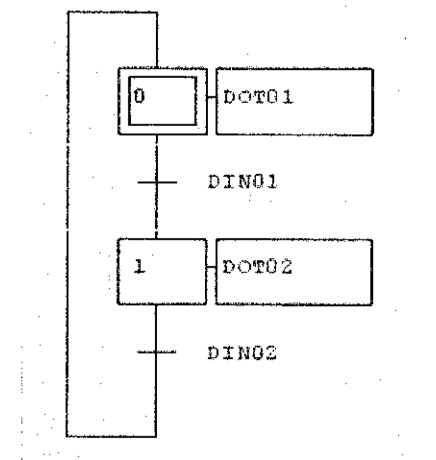
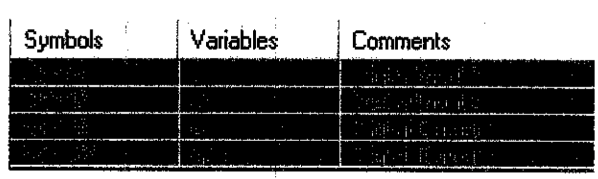


Figure 4.2: Grafcet with assigned symbols



Symbols	Variables	Comments
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

Figure 4.3: Symbols

Symbols is like the simplification of the input-outputs (I/Os) that will be assigned in Grafcet. Having the Symbols, makes the design looks neat and the I/Os will be much easier to assign.

4.1.2 OR and AND

The OR and AND operation via Grafcet are depicted in Figure 4.4 and Figure 4.5 respectively.

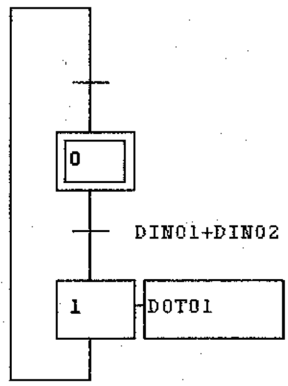


Figure 4.4: OR

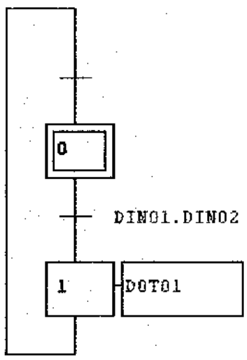


Figure 4.5: AND

To achieve OR, '+' is assigned as shown in Figure 4.4 and to achieve AND, '.' is assigned as shown in Figure 4.5. DIN and DOT in the figures are the acronym for digital input and digital output respectively. As in Figure 4.4, for DOT01 to on, either DIN01 or DIN02 is on. As in Figure 4.5, both DIN01 and DIN02 are on for DOT01 to on.

4.1.3 Timer

Method to implement timers in Grafcet is depicted clearly in Figure 4.6. The syntax used for timer is T1 (10s) and T2 (10s). The operations of these timers are discussed in details in section 4.4.5.1 at page 41.

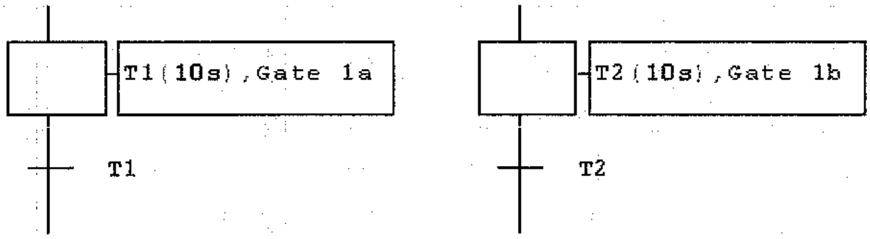


Figure 4.6: Timer

4.1.4 Force-to-Stop Technique

This particular force-to-stop technique will allow the steps that are running in the Grafcet to be stopped by force. This technique is utilized in the development of the TGCS to stop the gates and weirs operation during the SCADA control mode, manual control mode, preload conditions and to stop the TGCS process. Figure 4.7 shows how the force-to-stop is implemented in the TGCS design.

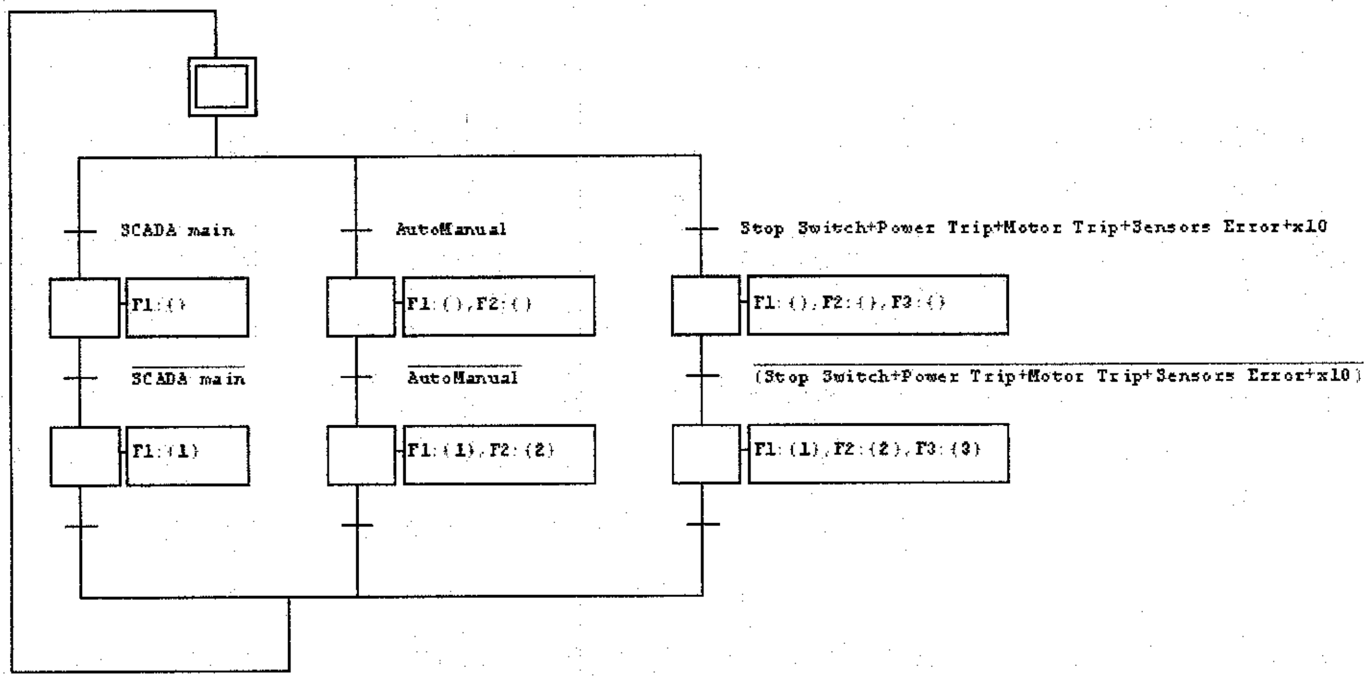


Figure 4.7: Force-to-stop technique in Grafcet

The syntax for SCADA control mode is F1:{}. The syntax for auto/manual control mode is F1:{} F2:{} and the syntax for preload conditions mode and stop the TGCS process are F1:{} F2:{} F3:{}. The operation of this technique and how it is operated is discussed in the following section 4.4.2.1, 4.4.3.1 and 4.4.6.1.

4.1.5 Destination and Source Steps, Destination and Source Transitions

This Grafcet programming technique is best known as 'jump-to' operation. The method to achieve the jump-to operation is shown in Figure 4.8.

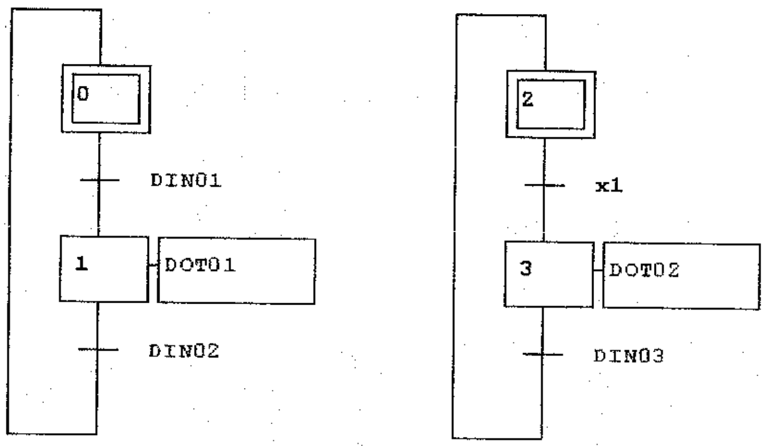


Figure 4.8: Jump-to operation in Grafcet

Refer to the transition after initial step 2, 'x1' is utilized to show that it needs an input from step 1. When step 1 (DOT01) is running, this output will become an input and jump to x1 to start the step 3 (DOT02).

4.2 Communication of Automgen7 with Omron PLC

For the communication to be established, the Omron PLC settings which include port, speed, parity and stop bits should be the same with the settings in the Omron Post Processor communication module in Automgen7. Figure 4.9 shows the Omron Post Processor communication settings and Appendix E shows the Omron PLC CQM1H SYSMAC Way communication settings. The communication settings is just valid for Omron PLC CQM1H type only.

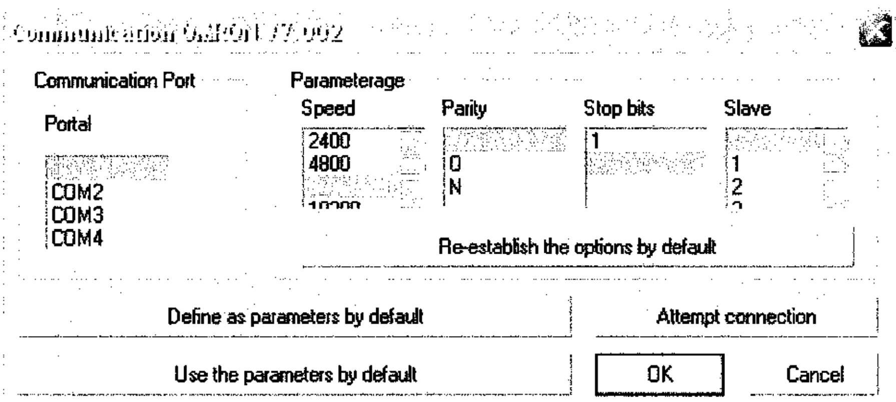


Figure 4.9: Omron post processor communication settings

For Omron PLC to acknowledge the digital output addresses assigned at Automgen7, setting under Linear Assignment, (Only for C) at o0 needs to be changed into 10000 as shown in Figure 4.10.

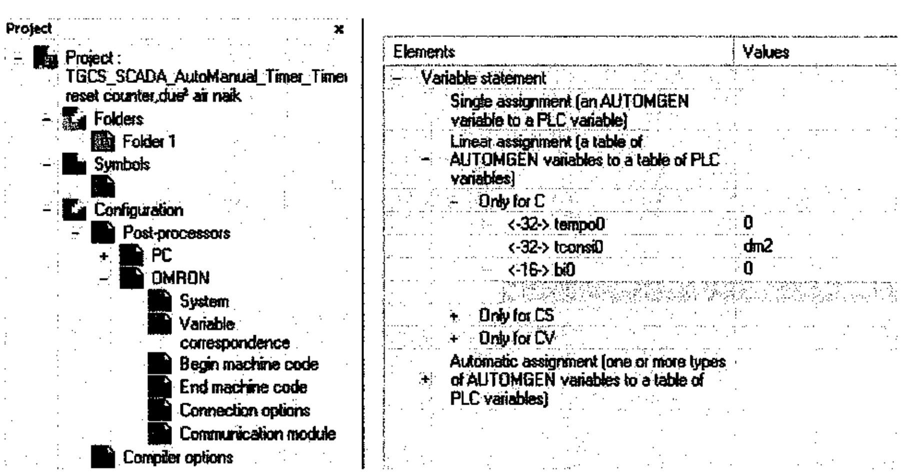


Figure 4.10: Setting to make Omron PLC acknowledges digital output addresses assigned at Automgen7

4.3 Communication of Adroit6 with Omron PLC

There are two methods in achieving the communication; using Adroit Omron Sysmac Protocol Driver and utilizing OPC Server as a middleware. Either Adroit Omron Sysmac Protocol Driver or OPC Server should be running one at a time to prevent from communication failure.

4.3.1 Adroit Omron Sysmac Protocol Driver

The Adroit Omron Sysmac Protocol Driver provides connectivity to Omron PLC C200, C1000 and CS1. Adroit Omron Sysmac Protocol Driver also support connection with CQM1H type although the particular PLC type does not listed under this driver. Figure 4.11 shows the required settings for PLC CQM1H type and Appendix E shows the Omron PLC CQM1H SYSMAC Way communication settings.

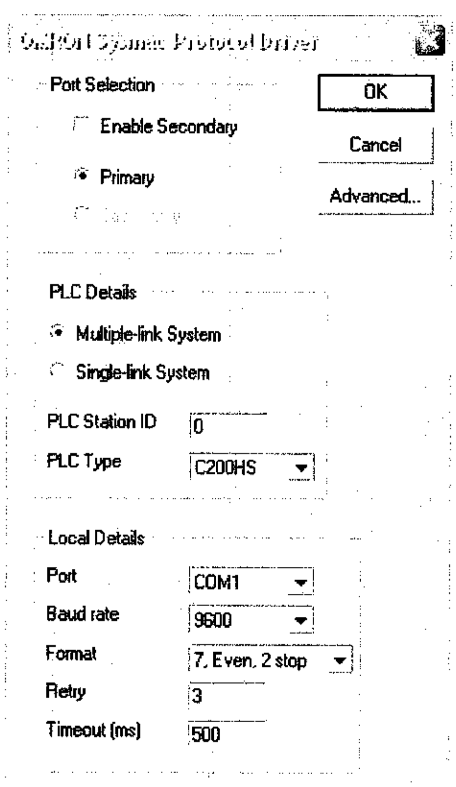


Figure 4.11: Adroit Omron Sysmac Protocol Driver settings

C200HS PLC type is selected for CQM1H. Local settings of CQM1H are made sure to be the same with Omron Sysmac Protocol Driver's. This is to offer synchronization and healthy communication.

OPC Server can be ignored once this particular communication is selected. Utilizing the driver, Adroit and Omron PLC manage to communicate without having a middleware software.

4.3.2 KEPware Enhanced OPC/DDE Server

KEPware OPC Server provides another method to achieve communication between Adroit and Omron PLC. It supports serial and Ethernet connectivity to the widest range of industrial control systems including: Allen Bradley, AutomationDirect, BACnet, GE, Honeywell, Mitsubishi, Modicon, Omron, Siemens, Texas Instruments, Yokogawa and many more. The KEPware OPC Server's job is to get Omron's device and system data and translate it into a standard communication protocol (OPC or DDE) that client (Adroit6) can receive and understand.

Appendix F shows the KEPware Enhanced OPC/DDE Server communication settings. The settings are the same as the Omron PLC CQM1H settings as shown in Appendix E. This is to offer synchronization and healthy communication between OPC Server and Omron PLC.

Using KEPware OPC Server is more preferable compare to Adroit Omron Sysmac Protocol Driver due to several reasons:

i. Tag names, addresses and data types can be assigned conveniently
   - Adroit can easily access and scan the assigned tag names from KEPware OPC Server
   - Any correction and changes of tag names, addresses and data types can be performed at KEPware OPC Server level and no rescanned of altered points required by Adroit

ii. OPC Quick Client featured by KEPware OPC Server offers the users to perform the tags monitoring job conveniently.
   - Utilizing the Adroit Omron Sysmac Protocol Driver will limit the monitoring jobs of the tags

Table 4.1 shows the memory area structure of CQM1H need to be applied to have a successful data acknowledgment by KEPware OPC Server. 5 data areas as shown in the table above are utilized greatly in the TGCS implementation.

Table 4.1: Memory area structure of CQM1H

Data Area	Data Type	Bits
Digital input	Boolean	IR000.00 to IR015.15
Digital output	Boolean	IR100.00 to IR115.15
Analog input	Word	IR220.00 to IR223.15
Data Memory (DM)	Word	DM0000 to DM6655
Timer/Counter	BCD	RC000 to RC511

4.4 TGCS Design via Grafcet and LD

TGCS design includes the following specifications:

i. Acknowledge analog inputs
ii. Auto/Manual Control Mode
iii. SCADA Control Mode
iv. Gates Sequences and Weir Sequences
v. 10s delay-to-close for Gate 1a and Gate 1b
vi. Preloads Condition

2 analog inputs, 13 digital inputs, 6 virtual digital inputs (VDIN), 6 digital outputs, and 6 timers are required to achieve the specifications. Table 1, Table 2, Table 3 and Table 4 in the Appendix B show the I/Os of TGCS and their respective CQM1H PLC address. The details of each TGCS specifications and the I/Os are explained in the following sections.

4.4.1 Analog Inputs

The river LT and the pond LT are represented by analog inputs available in the Omron PLC analog inputs module. Two analog inputs with their address 232 and 233 are utilized. Constant values or set points are fixed which indicate the threshold for the level transmitters to active. Thus, whenever the analog inputs value exceeds the set points, gates and weirs will either open or close.

The range of the CQM1H analog inputs is between &0 to &2047. The & sign is representing word data type in CQM1H. In the TGCS design, the set point for both river LT and pond LT is set to &1650 which equivalent to 80% at SCADA level.

4.4.1.1 Analog Inputs via Grafcet

In Grafcet, Analog inputs are assigned to Automgen word. The syntax for analog input with its address 232 is, m232 or % mw232 with 16bit words.

In order for Grafcet to acknowledge CQM1H's analog inputs, the Automgen words need to assigned to the targeted CQM1H's analog inputs, for instance, m232 (Automgen word) is assigned to 232 (CQM1H targeted address). Once the first Automgen word has been assigned to its respective Omron targeted address, the next Automgen words do not need to be assigned. Figure 4.12 depicts how the assignment of m232 is conducted in Automgen7.

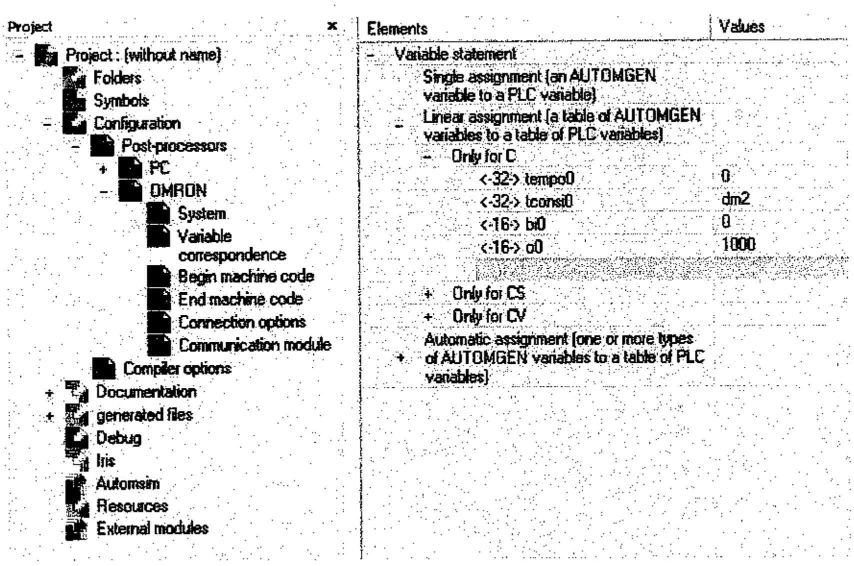


Figure 4.12: Associating Automgen word to the targeted CQM1H analog input

Under the Elements column, 16 bits of Automgen word with its address m232 is inserted and the targeted analog input address (232) is inserted under the Values column.

Once the Automgen word has been assigned, Grafcet can be programmed and the analog inputs from Omron PLC can be acknowledged by Grafcet. The comparison between analog input and set point via Grafcet is shown in Figure 4.13.

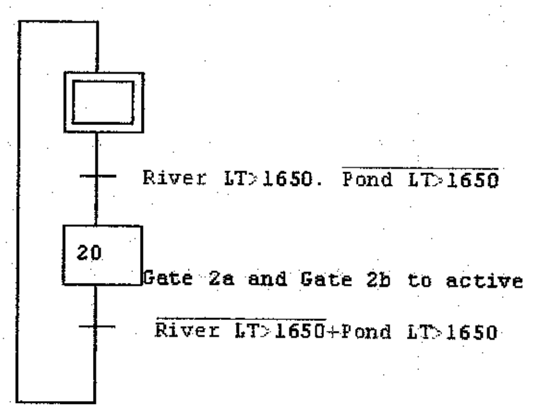


Figure 4.13: Comparison of river LT and pond LT with a set point

The Grafcet tells that if river LT is greater than 1650 and pond LT is not greater than 1650, move to step 20. Step 20 is used in the program as the transition input (jump-to operation) for Gate 2a and Gate 2b to active. The utilization of step 20 is discussed in section 4.4.2.1.

4.4.1.2 Analog Inputs via LD

The comparison between analog input with set point via LD is achieved by utilizing Compare (20), CMP(20) instruction. Figure 4.14 shows the CMP(20) instruction developed using CX-Programmer and how the comparison of river LT with a set point is performed.

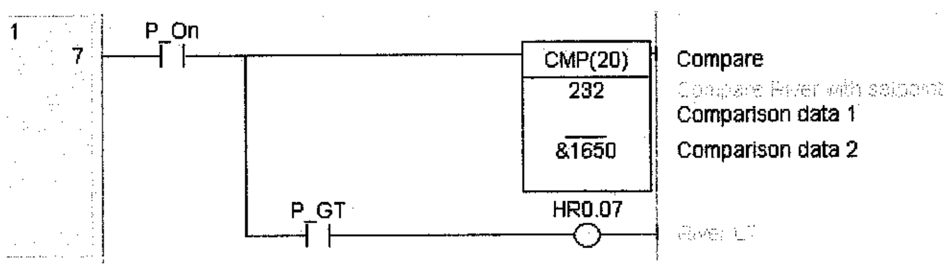


Figure 4.14: Comparison of river LT with a set point

Figure 4.14 also shows the P_GT (Greater Than) instruction is used. Base on the above LD, if 232 (river LT) is greater than &1650, HR0.07 is contacted.

4.4.1.3 Comparison between Grafcet and LD

Certain settings need to be configured in Automgen7 in order for Grafcet to acknowledge analog inputs. By having in mind that Automgen7 needs to communicate with PLC that is manufactured by different manufacturer, of course certain settings need to be configured. The acknowledgement of analog inputs by CX-Programmer is simpler since the software was developed by the same manufacturer. As far as the objective of the project is concerned, the study of advantages and disadvantages of Grafcet over LD becomes the priority, rather than the advantages and disadvantages of the software to develop those programming.

To achieve the comparison of analog inputs with set point via Grafcet is simpler compared to LD. In LD, CMP(20) needs to be programmed and 'P_GT' syntax need to be used to have the 'Greater Than' instruction. While in Grafcet, it just requires '>' syntax for the 'Greater Than' instruction. The advantage of Grafcet maybe not very strong in this section since only 'Greater Than' instruction is required in the design. The advantage of Grafcet in implementing comparison programming technique is discussed in section 4.4.4 where 'Greater Than', 'Equal' and 'Lesser Than' instructions are utilized largely.

4.4.2 Auto/Manual Control Mode

Auto/Manual control mode will enable the system to be operated automatically and manually. To activate manual control mode, Auto/Manual Switch (item 3) as shown in Table 2 in Appendix B, should be at on or high (1) condition. When Auto/Manual Switch is off or low (0), automatic control mode is activated.

4.4.2.1 Auto/Manual Control Mode via Grafcet

Figure 1 in Appendix C shows automatic control mode via Grafcet for Gate 1a and Gate 1b. As in the figure, automatic control mode starts at step 1. Step 1 is the main control sequence of the gates and weirs in the TGCS design. When start switch is on (x40) and the river level is below than 1650 (/x20), it will move to the next step (refer to Figure 4.13 at page 28 for the x20 jump-to operation). Grafcet will select the lowest run-hour to open the gate.

Refer to Figure 4.7 at page 20, the force-to-stop syntax for AutoManual is F1:{},F2:{}, which means it will stop step 1 and step 2 by force if F1:{},F2:{} is high. Refer to Figure 1 in Appendix C, automatic control mode is assigned with step 1 and Figure 4.16 at page 35, shows SCADA control mode is assigned with step 2. Thus, automatic control mode and SCADA control mode are forced to stop when the AutoManual switch is on. Automatic control mode and SCADA control mode are forced to stop due to manual control mode is designed in TGCS to have higher priority than automatic control mode and SCADA control mode as discussed in section 1.4.1.2.

As the main control sequence of gates and weirs (step 1) is now off, the gates and weirs can be operated manually by having the manual control mode sequence as shown in Figure 4.15. Refer to Figure 4.15, when x40 and AutoManual are both high, Gate 1a and Gate 1b can be opened or closed by simply pressing their respective manual control button.

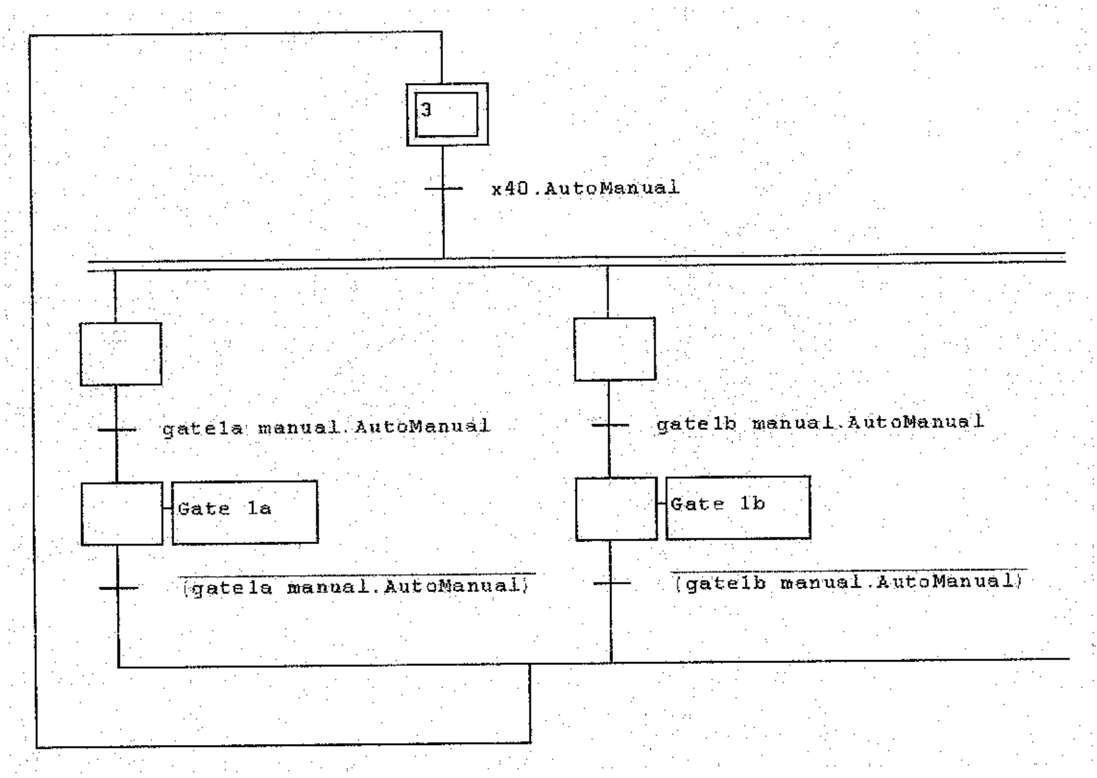


Figure 4.15: Manual control mode via Grafcet

4.4.2.2 Auto/Manual Control Mode via LD

Figure 2 in Appendix C shows how to achieve Auto/Manual control mode via LD. As in the figure, automatic control mode is achieved through contact HR0.01 at rung 13 and manual control mode is achieved through contact 0.03 (Auto/Manual Switch) at rung 14. When Auto/Manual switch is on, this will close Gate 1. To open the gate manually, 0.04 (Gate 1a Manual Switch) is pressed.

4.4.2.3 Comparison between Grafcet and LD

To achieve automatic control mode via Grafcet is simple compared to the LD. Compare the program to develop automatic control mode via Grafcet shown in Figure 1 in Appendix C with program to develop automatic control mode via LD shown in Figure 2 in Appendix C, obviously it takes less effort to develop the particular control mode by Grafcet. The program looks shorter and easy to understand. The logic controls develop via LD shown in the Figure 2 in Appendix C function exactly the same with the logic control develop via Grafcet shown in Figure 1 in Appendix C. Although the outcomes are the same but the method on how to achieve the outcomes are not. Moreover, LD shown in the figure is just for the Gate 1a and Gate 1b. The program becomes more lengthy and complicated when gates at Area 2 and weirs at Area 3 are included.

To achieve manual control mode by LD is easier compared to Grafcet. To achieve the manual control mode via LD, rung 14 in the Figure 2 in Appendix C is required. Force-to-stop command and additional control sequence need to be introduced in Grafcet in order to achieve manual control mode. Although extra works need to be performed in Grafcet, it is designed in such away for the future system expansions. With a slight alteration, the force-to-stop command able to memorize Grafcet steps.

4.4.3 SCADA Control Mode

In order to make Adroit to control the Omron PLC digital outputs, a variable at Omron PLC level that Adroit can control needs to be clarified. Variables that can be controlled by Adroit are virtual digital inputs (VDINs) and holding relay (HR). These variables will act as a medium so that the command from Adroit will execute the operation to control the on/off of the digital outputs. VDINs are the digital inputs that exceed the number of digital inputs provided by the I/O unit attached to the PLC. CQM1H PLC that being used for the project has 16 built-in inputs. Thus, the VDINs value should be more than 16. HR is where the data are stored and retained their on/off status when the power is turned off. The HR memory area for CQM1H is from HR 0000 to HR 9915.

It is preferable to utilize VDINs to manipulate the Omron PLC digital outputs. This is because VDINs can be recognized by both Cx-Programmer and Automgen7. For the project, VDIN with the value start from IR100 is utilized. Table 3 in Appendix B shows the CQM1H addresses utilized for SCADA control mode.

4.4.3.1 SCADA Control Mode via Grafcet

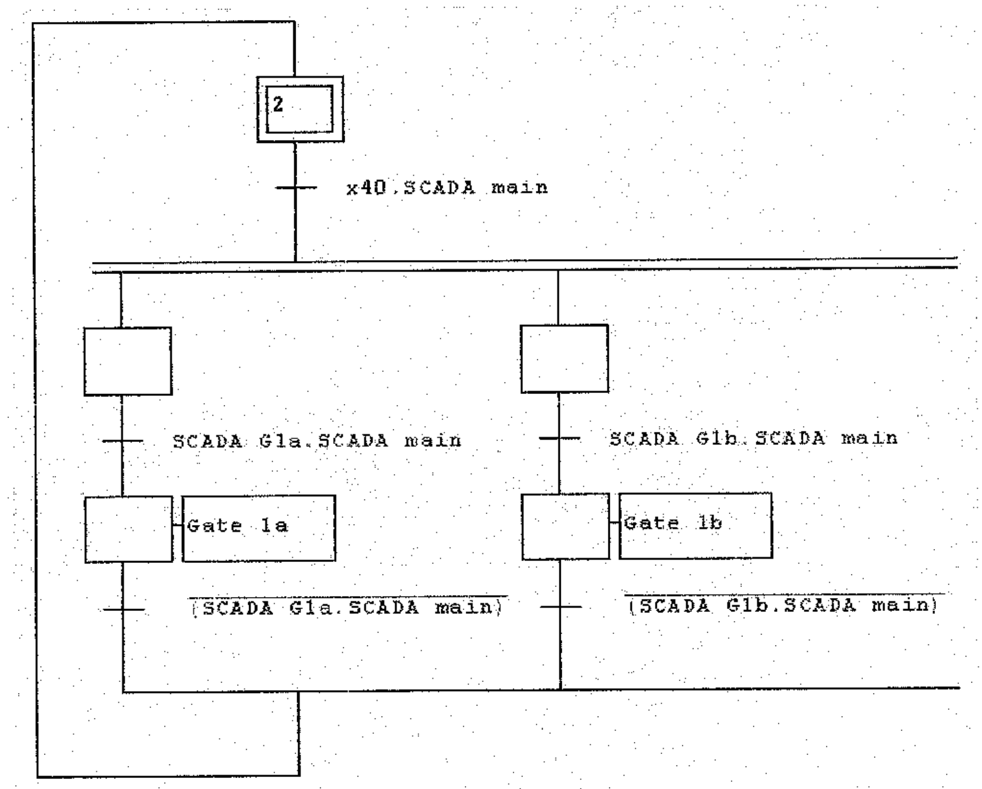


Figure 4.16: SCADA control mode via Grafcet

Refer to Figure 4.7 at page 20, the force-to-stop syntax for SCADA main is F1:{}, which means it will stop step 1 by force if F1:{} is high. Refer to Figure 1 in Appendix C, automatic control mode is assigned with step 1. Thus, automatic control mode is forced to stop when the SCADA main switch is on. Automatic control mode are forced to stop due to SCADA control mode is designed in TGCS to have higher priority than automatic control mode as discussed in section 1.4.1.3.

As the main control sequence of gates and weirs (step 1) is now off, the gates and weirs can be operated remotely by having the SCADA control mode sequence as shown in Figure 4.16. Refer to Figure 4.16, when x40 and SCADA main are both high, Gate 1a and Gate 1b can be opened or closed by simply pressing their respective control button provided at the TGCS SCADA mimic.

4.4.3.2 SCADA Control Mode via LD

Refer to Figure 2 in Appendix C, at rung 14, again SCADA control mode is achieved by having 1.00 (Auto/ SCADA Mode). When Auto/ SCADA Mode button from Adroit6 is on, this will close Gate 1a. To open the gate remotely, 1.01 (SCADA Gate 1a) should be on.

4.4.3.3 Comparison between Grafcet and LD

Basically the approach to achieve SCADA control mode and manual control mode is somewhat the same. In LD, rung 14 in Figure 2 in Appendix C is required to achieve both control modes. Force-to-stop command and additional control sequence are also required in Grafcet in order to achieve SCADA control mode. To achieve manual control mode, LD is the preferable method due it requires simple approach and does not need extra control sequences as Grafcet requires.

4.4.4 Gates Sequence and Weirs Sequence

Gates sequence and weirs sequence are one of the design specifications under automatic control mode. This particular specification is based on lowest run-hour. Gate and weir with the lowest run-hour has the priority to open. This is to ensure the actuator of the gates and weirs can be operated as long as possible before it reaches its lifetime.

4.4.4.1 Gates Sequence and Weirs Sequence via Grafcet

The total run-hour of all gates and weirs is recorded by the system. Figure 4.17 shows how the run-hour of Gate 1a and Gate 1b is incremented and recorded. The purpose of T0 is to count 1 second. Thus, every 1 second of the run-hour of each gate, is incremented and recorded at '+gate1a cntr' and '+gate1b cntr'.

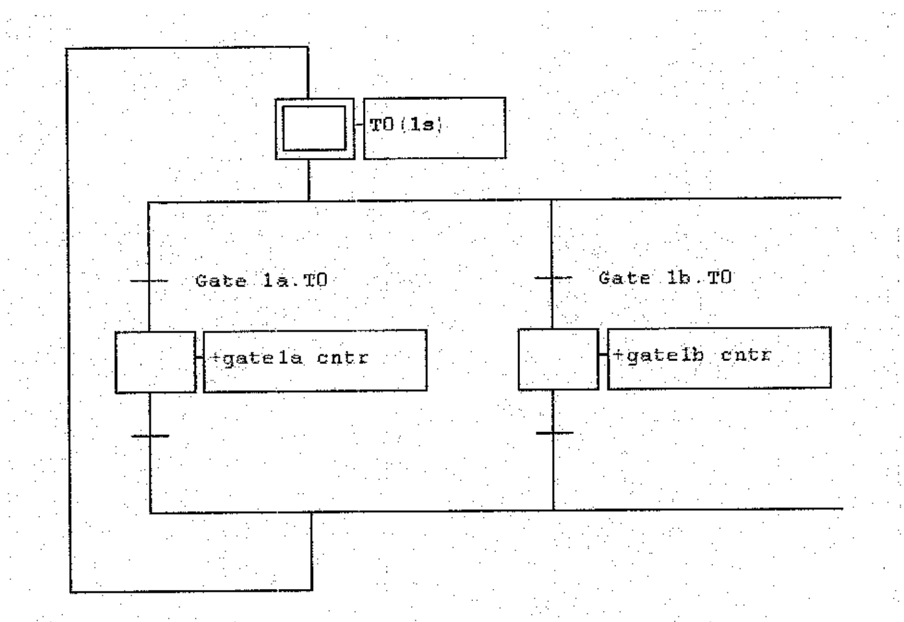


Figure 4.17: Gate 1a and Gate 1b sequence via Grafcet

Refer to the automatic control mode via Grafcet shown in Figure 1 in Appendix C, if gate1a cntr is less or equal to gate1b cntr, means Gate 1a run-hour is equal or less than Gate 1b, Gate 1a will be opened. If gate1a cntr is bigger than gate1b cntr, means Gate 1b has lower run-hour than Gate 1a, Gate 1b will be opened.

4.4.4.2 Gates Sequence and Weirs Sequence via LD

Figure 4.18 shows how to achieve gates sequence and weirs sequence via LD.

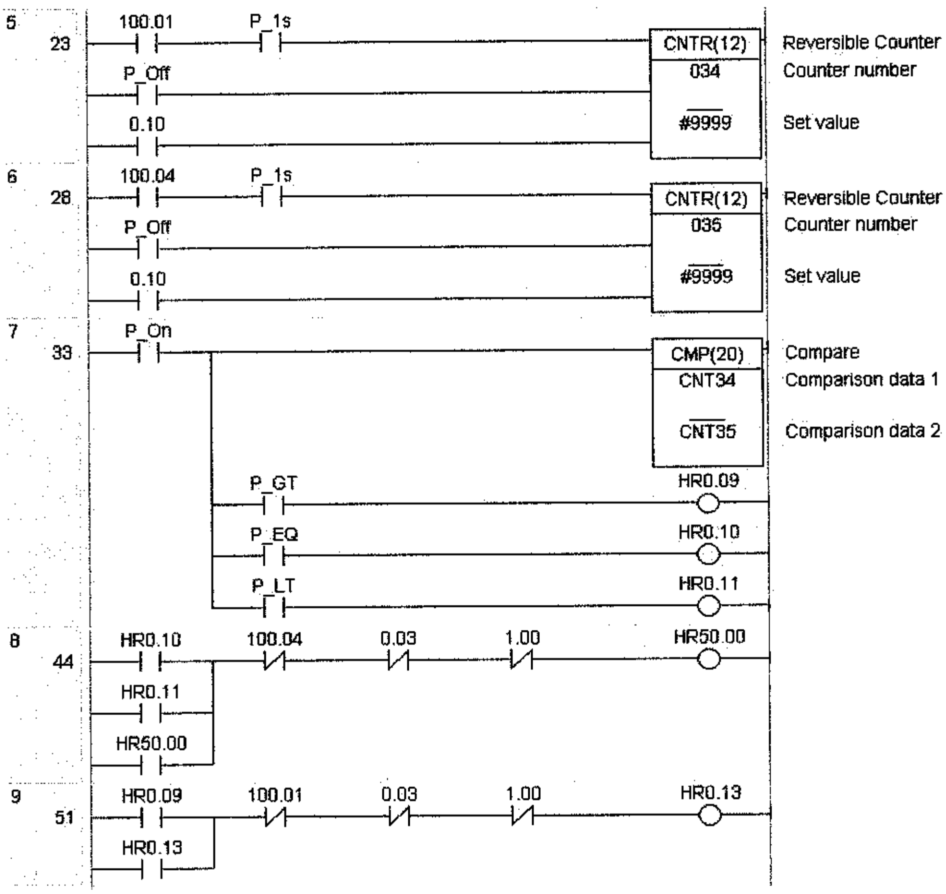


Figure 4.18: Gate 1a and Gate 1b sequence via LD

Reversible Counter 20 (CNTR 20) instruction list is utilized to increment the gates and weirs run-hour. Figure 4.18 shows that counter 034 and counter 035 are used which represents Gate 1a run-hour and Gate 1b run-hour respectively. Refer to Figure 4.18 at rung 5, 100.01 (Gate 1a), is the input to increment the counter number 34 up to its set value (#9999). P_Off is the input to decrement the counter and 0.10 (Reset Timer Switch) is the input to reset the counters. In gates sequence and weirs sequence, decrement of counter is not in the design consideration, thus input P_Off is selected in order to make no decrement of counter to occur.

To increment counter 034 and counter 035 with one second increment, P_1S command is used. CMP(20) instruction is used to compare the total value of run-hour between Gate 1a and Gate1 b. P_GT is used to make HR0.09 to contact if Gate 1a run-hour is greater than Gate 1b. P_EQ is used to make HR0.10 to contact if total gate run-hour of those two is equal and P_LT is used to make HR0.11 to contact if Gate 1a run-hour is lesser than Gate 1b.

In order for LD to the have history of pulse inputs in HR0.09, HR0.10 and HR0.11, latch needs to be included. HR0.10 and HR0.11 are latched with HR50.00. This control logic tells that when Gate 1a run-hour is less than or equal to the Gate 1b run-hour, latch the HR50.00. Refer to the automatic control mode via LD shown in Figure 2 in Appendix C, at rung 10, HR50.00 is utilized to be one of the inputs to trigger the Gate 1a. HR0.09 is latched with HR0.13 which explains latch the HR0.13 when Gate 1a run-hour is greater than Gate 1b run-hour. Refer to the automatic control mode shown via LD in Figure 2 in Appendix C, at rung 15, HR0.13 is utilized to be one of the inputs to trigger the Gate 1b.

The latched HR50.00 and HR.013 needs to be unlatched. Inputs are required to unlatch HR50.00 are 100.04 (Gate 1b), 0.03 (Auto/Manual Switch) and 1.00 (Auto/SCADA) while inputs are required to unlatch HR0.13 are 100.01 (Gate 1a), 0.03 (Auto/Manual Switch) and 1.00 (Auto/SCADA). If any of these digital inputs is on, HR50.00 and HR0.13 are unlatched.

4.4.4.3 Comparison between Grafcet and LD

To achieve gates sequence and weir sequence via LD is very challenging. It involves a great utilization of data comparison, HRs, latch and unlatch. For the data comparison, command P_GT, P_EQ and P_LT are required to have 'Greater Than', 'Equal' and 'Lesser Than' instruction. These commands are required to be latched and unlatched and this will contribute to the extra usage of HRs. Moreover, the program becomes lengthier and the flow becomes harder to understand when gates at Area 2 and weirs at Area 3 are included. To achieve data comparison in Grafcet as shown in Figure 1 in Appendix C, '>' and '<=' are required to have 'Greater Than', 'Equal' and 'Lesser Than' instruction. The program looks simpler, shorter and easier to understand and to troubleshoot.

4.4.5 10 seconds delay-to-close

10 seconds delay-to-close for Gate 1a and Gate 1b falls under the automatic control mode as well. Delay for Gate 1a and Gate 1b to close is introduced for the water from housing scheme to flow in two directions: to the river and to the pond in a short period of time. This will ensure that the water level at the housing scheme at a safe level. After Gate 2a or Gate 2b is fully opened, Gate 1a or Gate 1b will be closed and the water from housing scheme is channeled to the pond. Gate 2a and Gate 2b are estimated to be fully open within 10 seconds.

4.4.5.1 10 seconds delay-to-close via Grafcet

Refer to Figure 4.6 at page 19, T1 (10s) and T2 (10s) are introduced for Gate 1a and Gate 1b, respectively. Thus, those gates will have 10 seconds delay before the gates are closed. 10 seconds delay-to-close via Grafcet is shown in Figure 1 in Appendix C as well.

4.4.5.2 10 seconds delay-to-close via LD

Figure 4.19 depicts how LD is programmed to achieve 10 seconds delay for Gate 1a.

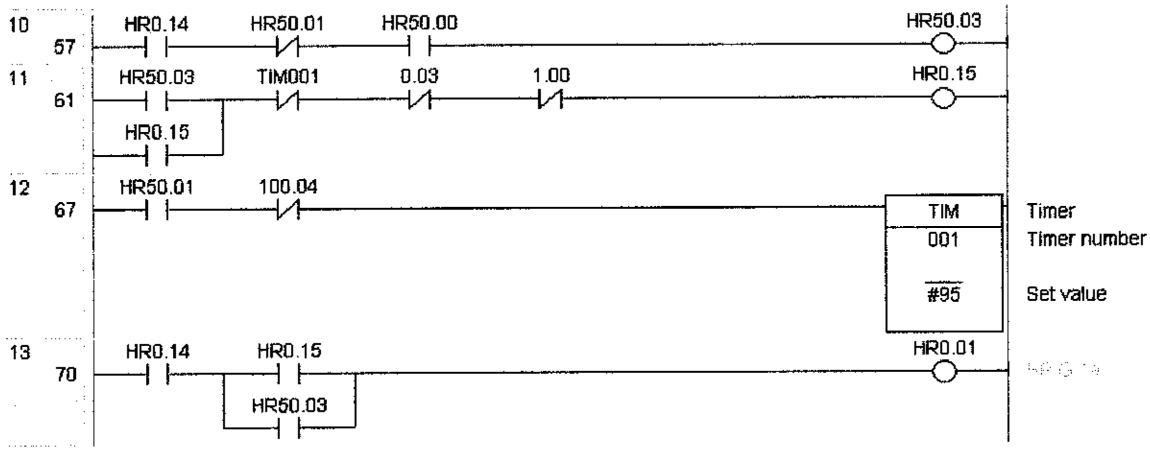


Figure 4.19: 10 seconds delay-to-close for Gate 1a via LD

Rung 13 at Figure 4.19 is the rung to achieve automatic control mode for Gate 1a via LD. When HR50.01 is contact (the river LT is high), it will start the timer. The set value of the timer is #95 which approximately equal to 10 seconds. After 10 seconds has elapsed, the latched HR0.15 will be unlatched and HR0.01 is not contacted (Gate 1a is close).

4.4.5.3 Comparison between Grafcet and LD

In LD, it is reasonably take a longer way to introduce timer in the system. It requires HR, latch and unlatch which tend to make the LD program lengthy and difficult to follow and troubleshoot. Introducing timer via Grafcet is simple and convenient.

4.4.6 Preloads Condition

Table 2 in Appendix B shows the digital inputs and their respective address that are utilized for preloads condition. The preloads condition inputs are the item 11, 12 and 13 shown in the table. If any of these inputs is high, the TGCS operation is stopped.

4.4.6.1 Preloads Condition via Grafcet

Refer to Figure 4.7 at page 20, the force-to-stop syntax for Stop Switch, Power Trip, Motor Trip and Sensors Error is F1:{},F2:{},F3:{}, which means it will stop step 1, step 2 and step 3 by force if F1:{},F2:{},F3:{} is high. Refer to Figure 1 in Appendix C, Figure 4.16 at page 35 and Figure 4.15 at page 32 where automatic control mode, SCADA control mode and manual control mode are assigned with step 1, step 2 and step 3 respectively. Thus, these control modes are forced to stop when either of Stop Switch, Power Trip, Motor Trip or Sensors Error is on. In order to start the TGCS operation, Start Switch is pressed.

4.4.6.2 Preloads Condition via LD

Figure 4.20 depicts how to achieve preloads condition and stop switch via LD.

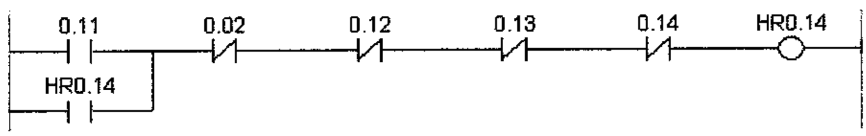


Figure 4.20: Preloads condition and stop switch via LD

Latch and unlatch are utilized to achieve this particular design specification. When 0.11 (Start Switch) is contacted, HR0.14 is latched. 0.12, 0.13, 0.14 (preloads condition inputs) and 0.02 (Stop Switch) are required to unlatch the HR0.14. If any of these inputs is contacted, HR0.14 is unlatched.

4.4.6.3 Comparison between Grafcet and LD

To achieve this design specification via LD is easier compared to Grafcet. In Grafcet, force-to-stop command needs to be introduced.

4.5 TGCS SCADA

SCADA will offer the TGCS to be viewed in graphical representation. The behavior or the values of digital inputs (switches and sensors), digital outputs (gates and weirs) and analog inputs (river LT and pond LT) can be monitored remotely by SCADA. The operation of gates and weirs can be controlled remotely via SCADA as well. The TGCS SCADA is designed to provide some features which are discussed in the following sections.

4.5.1 Security Login

Security in Adroit6 makes use of Windows security. TGCS allows two users to access the system: administrator and quest. Administrator has the higher access and control level than quest. SCADA control buttons in the TGCS SCADA can only be operated by the administrators. If the administrators login into the TGCS, the particular users are required to key in the password. Login page of TGCS is shown in Figure 1 in Appendix D.

4.5.2 TGCS Mimics

Two mimics of TGCS have been designed which are home and area. Home mimic shown in Figure 2 in Appendix D, provides the users to monitor the behaviors of river level, pond level, gates and weirs. Area mimic that is depicted in Figure 3 in Appendix D, allows users to monitor the gates and weirs total run-hour and to control the gates and weirs remotely by clicking the SCADA control buttons provided at the bottom of the mimic.

4.5.3 Alarm

Alarm is displayed in the alarm window as shown in Figure 4 in Appendix D. The particular figure shows that river level is currently high with its capacity is 84.42% full. River level and pond level are configured in SCADA level to provide alarm high if their capacity is 80% to 90%. Alarm high-high will be triggered if river level and pond level are higher than 90% capacity. Preloads condition alarm are also configured in the SCADA. Alarm is reported in the alarm window if any of the preloads condition is high.

4.5.4 Event

Event window as shown in Figure 5 in Appendix D reveals all the events that occurred in Adroit6 and KEPware OPC Server.

4.5.5 Trend

In TGCS SCADA design, the trends of river LT and pond LT is configured and displayed in the trend window as shown in Figure 6 in Appendix D. In the figure, river level is represented in red colour and pond level is represented in green colour. Trend window also provides the information of the current value, minimum, maximum and the average value of the assigned tags.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This report discusses several issues of developing a controller using PLC via Grafcet and LD. In particular it attempts to answer several questions that are as follows:

- what knowledge is required to design a Grafcet programming?
- how to construct a workable process controlled via Grafcet and LD programming?
- what are the advantages and disadvantages of Grafcet over LD?
- how to monitor and control the workable process via Supervisory Control and Data Acquisition (SCADA)?

TGCS has been developed to understand the advantages and disadvantages of Grafcet over LD. Data comparison and timer programming techniques implementation in TGCS is more conveniently develop via Grafcet compared to LD. However, the implementation of manual control mode, SCADA control mode, preloads condition and stop switch via Grafcet is not preferable as additional control sequences are required. Although extra works need to be performed in Grafcet to design the additional control sequences, their developments are certainly convenient.

The project has shown that Grafcet has its credits compared to LD. Grafcet offers a convenient approach to the developments of the TGCS design specifications. Grafcet programming is shorter, and the flows of control sequences are indeed understandable, easy to troubleshoot and easy to expand for future designs.

The project has shown that monitoring and control of TGCS by SCADA can be performed. The trending, events and alarm of the system are monitored and the operation of gates and weirs can be controlled remotely by SCADA.

5.2 Recommendations

For future works, this project and investigation can be further continued with the following suggestions:

- Utilize RTU to replace PLC. RTU is the acronym of Remote Terminal Unit. It is capable to support wireless communication such as SMS communication and radio communication. The remote locations of gates and weirs to the control room makes the wired communication is not the preferable approach to work on. Utilizing RTU will reduce the cost of the system and offers more reliable communication.

- Develop TGCS prototype. The actual model or prototype can be developed to show the actual TGCS operations.

- Monitor and control of TGCS is performed by DCS. Expanding the current SCADA-controlled system to have Distributed Control System (DCS) elements.

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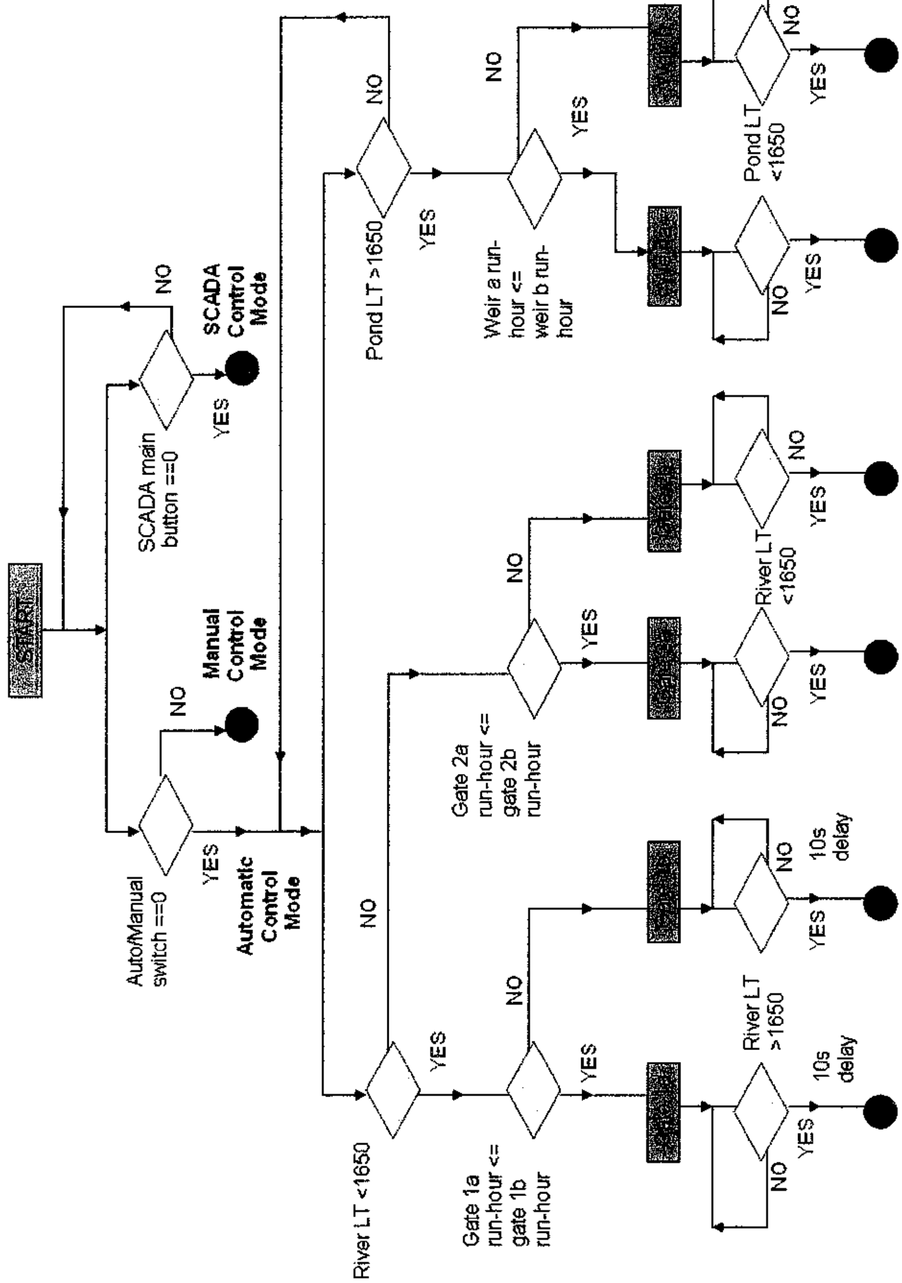
APPENDICES

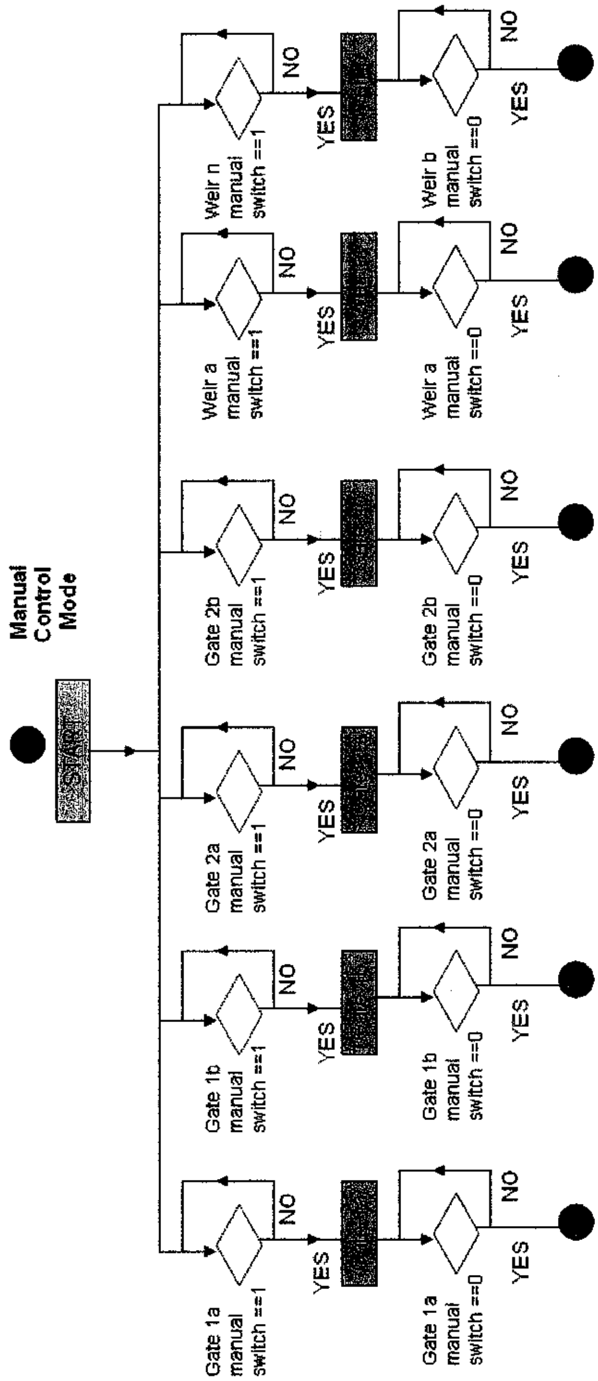
APPENDIX A

FLOWCHART 1: AUTOMATIC CONTROL MODE



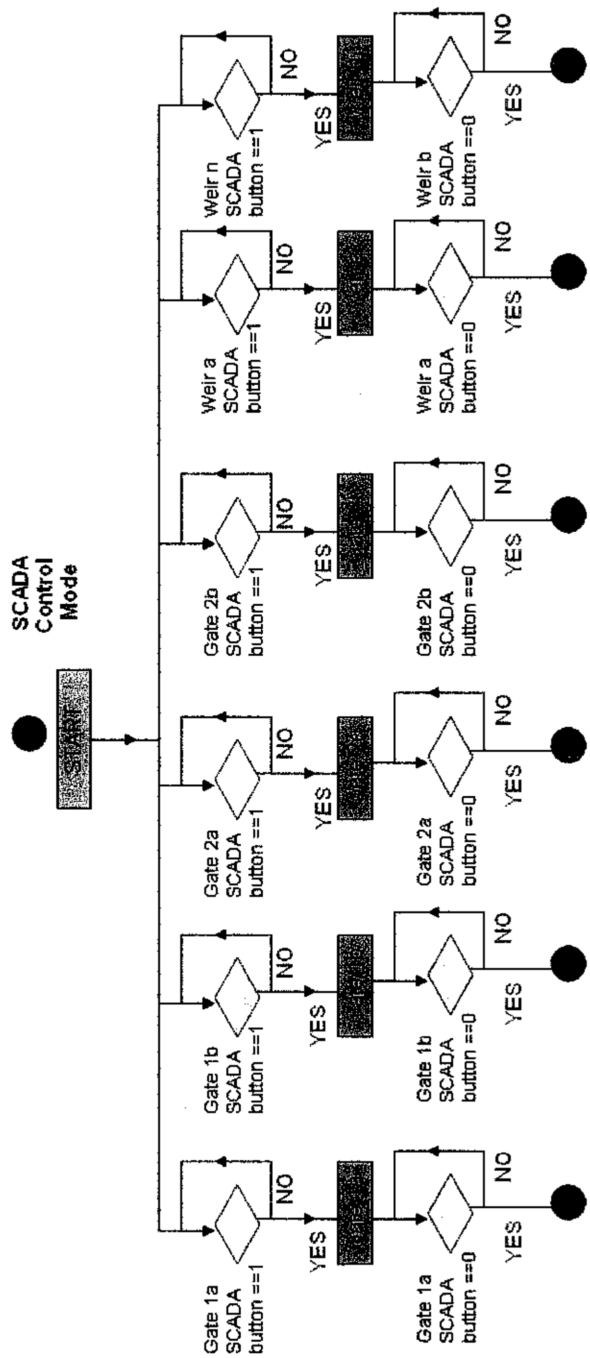
APPENDIX A

FLOWCHART 2: MANUAL CONTROL MODE



APPENDIX A

FLOWCHART 3: SCADA CONTROL MODE



APPENDIX B

TABLES: LIST OF TGCS I/Os AND CQM1H ADDRESSES

Table 1: Analog inputs and CQM1H address

Item	Analog inputs	CQM1H address
1	River LT	232
2	Pond LT	233

Table 2: Digital inputs and CQM1H address

Item	Digital inputs	CQM1H address
1	Start Switch	0.11
2	Stop Switch	0.02
3	Auto/Manual Switch	0.03
4	Gate 1a Manual Switch	0.04
5	Gate 2a Manual Switch	0.05
6	Weir a Manual Switch	0.06
7	Gate 1b Manual Switch	0.07
8	Gate 2b Manual Switch	0.08
9	Weir b Manual Switch	0.09
10	Reset Timer Switch	0.10
11	Power Trip	0.12
12	Motor Trip	0.13
13	Sensor Error	0.14

APPENDIX B

TABLES: LIST OF TGCS I/Os AND CQM1H ADDRESSES

Table 3: VDINs and CQM1H address

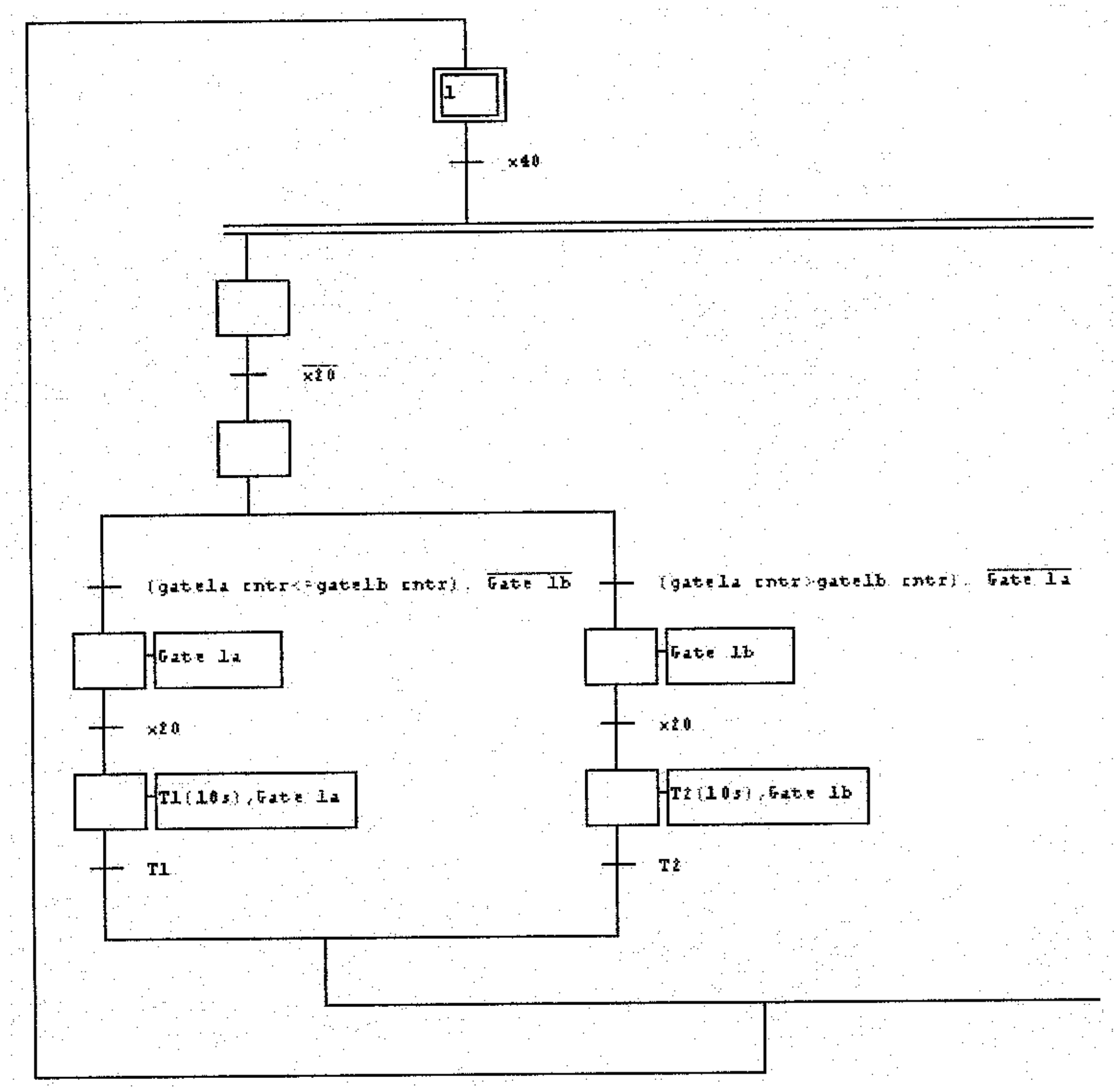
Item	VDINs	CQM1H address
1	Auto/ SCADA Mode	1.00
2	SCADA Gate 1a	1.01
3	SCADA Gate 2a	1.02
4	SCADA Weir a	1.03
5	SCADA Gate 1b	1.04
6	SCADA Gate 2b	1.05
7	SCADA Weir b	1.06

Table 4: Digital outputs and CQM1H address

Item	Digital outputs	CQM1H address
1	Gate 1a	100.01
2	Gate 2a	100.02
3	Weir a	100.03
4	Gate 1b	100.04
5	Gate 2b	100.05
6	Weir b	100.06

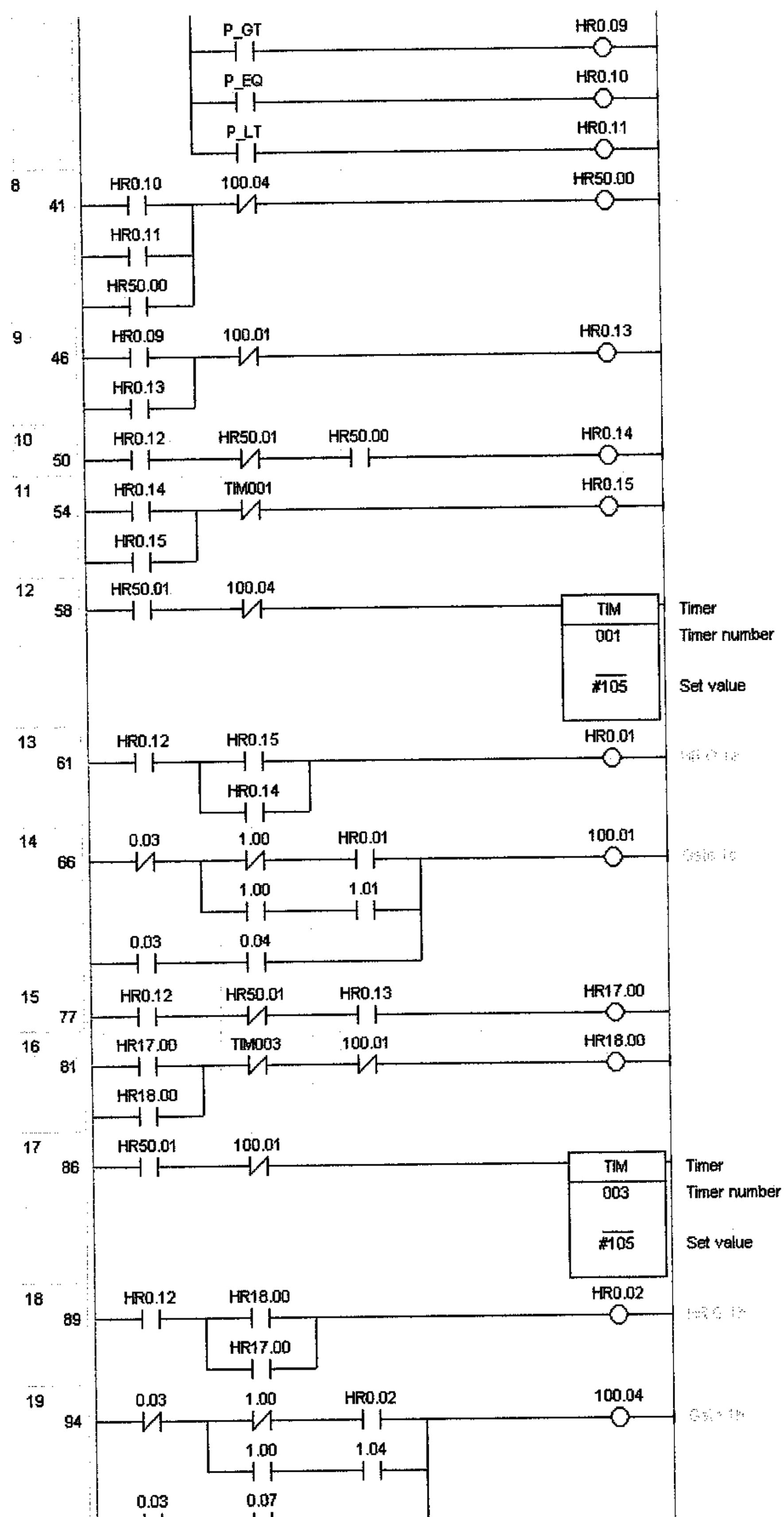
APPENDIX C

FIGURE 1: AUTOMATIC CONTROL MODE FOR GATE 1a AND GATE 1b - GRAFCET



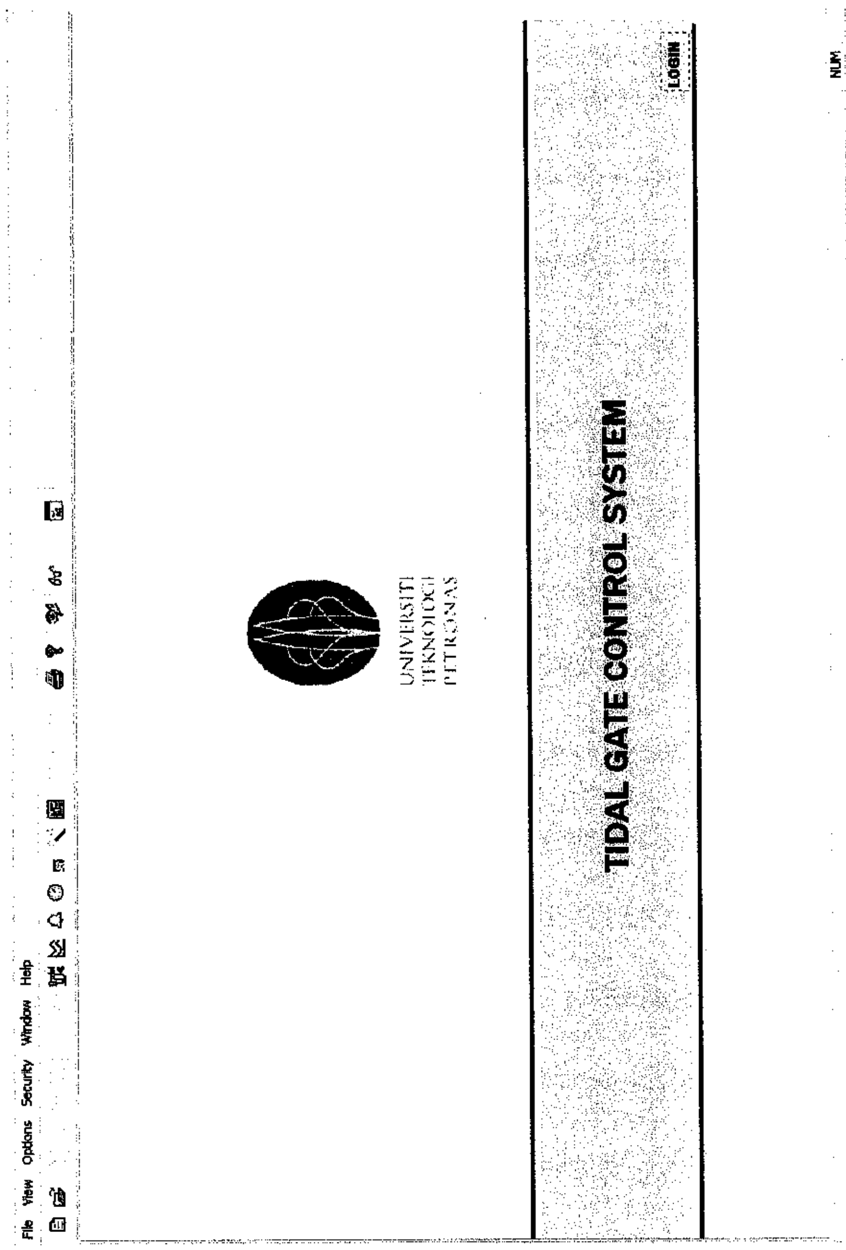
APPENDIX C

FIGURE 2: AUTOMATIC CONTROL MODE FOR GATE 1a AND GATE 1b - LD



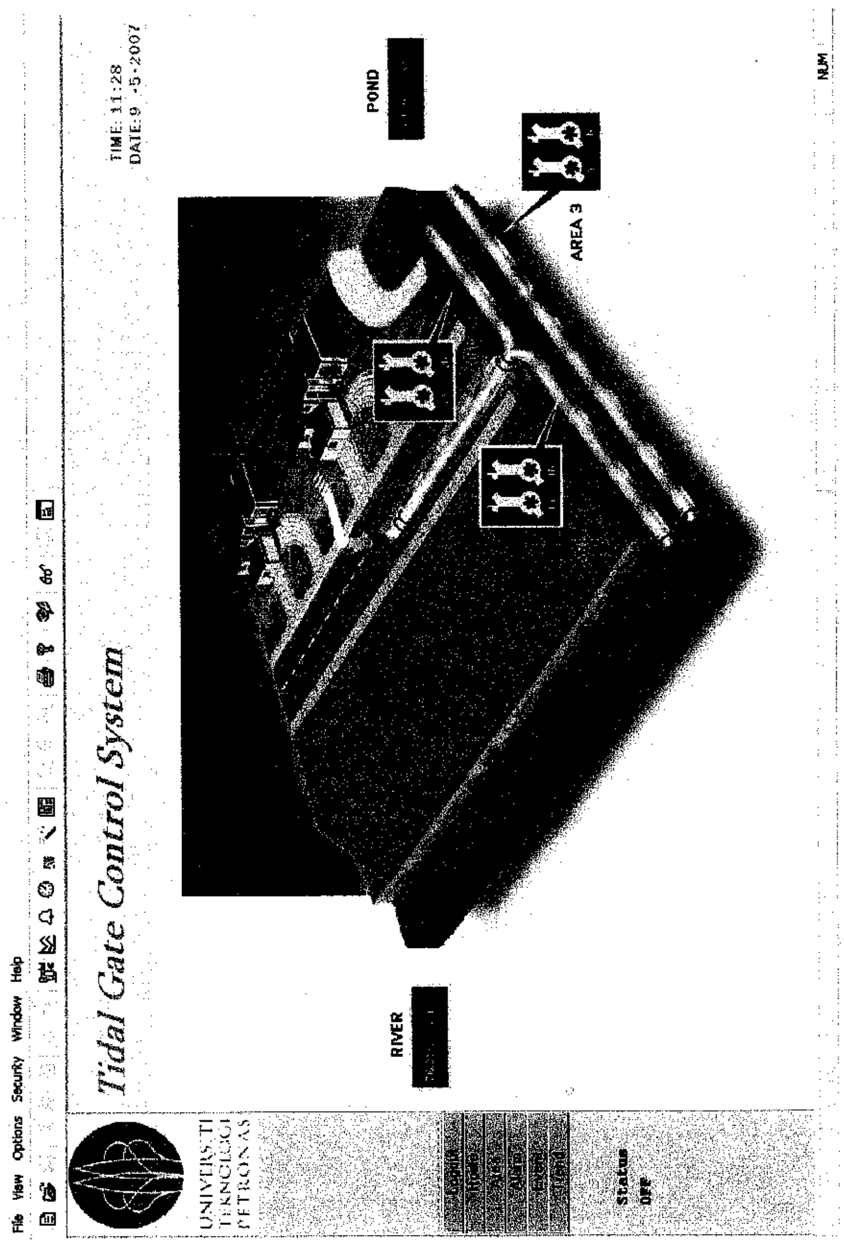
APPENDIX D

FIGURE 1: TGCS SCADA – LOGIN PAGE



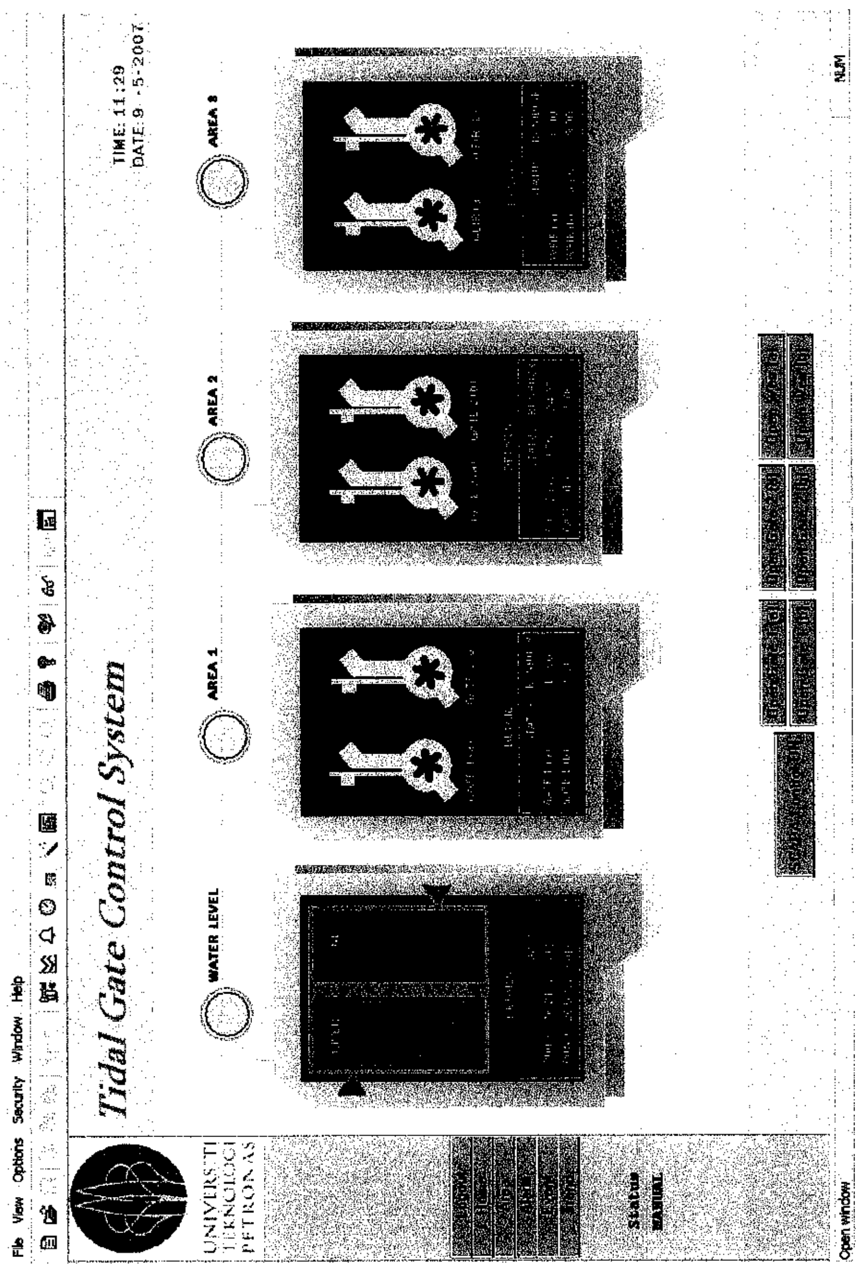
APPENDIX D

FIGURE 2: TGCS SCADA – HOME MIMIC



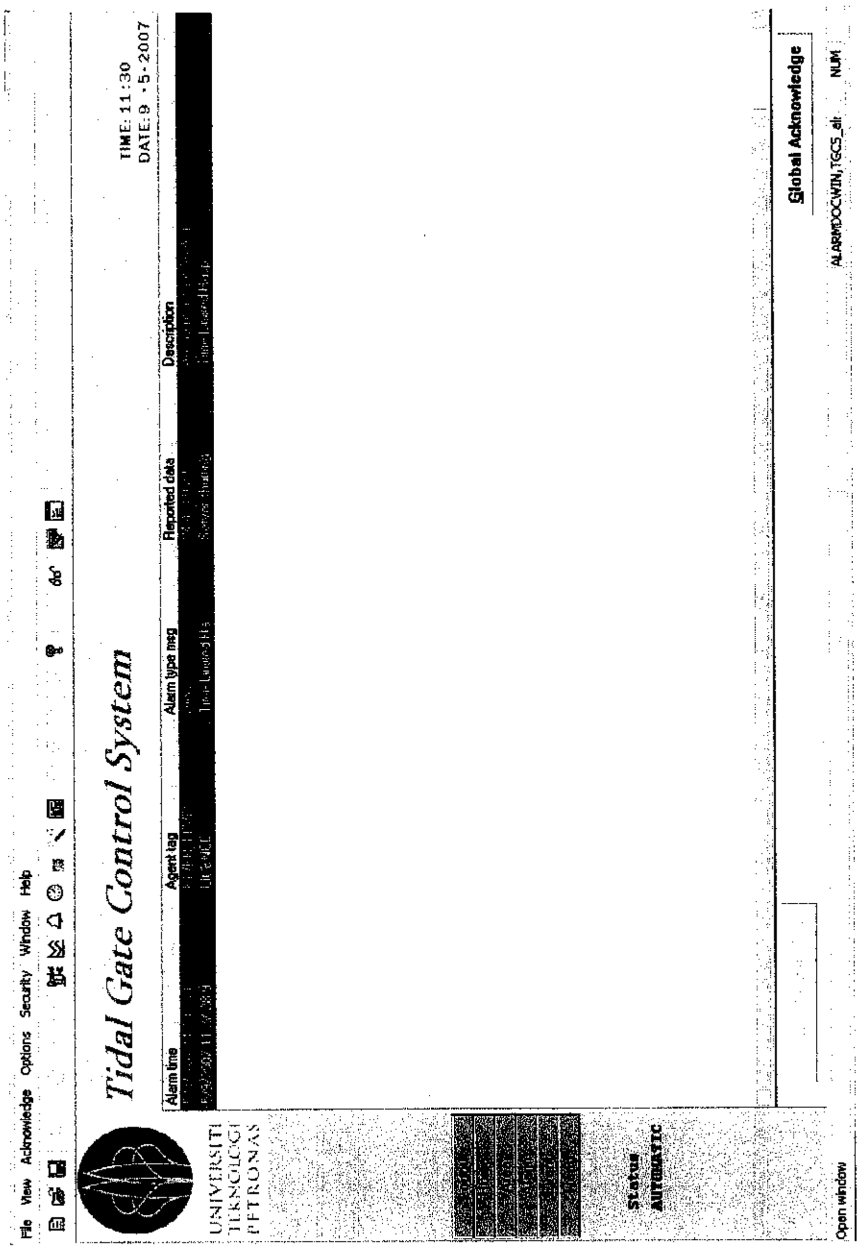
APPENDIX D

FIGURE 3: TGCS SCADA – AREA MIMIC



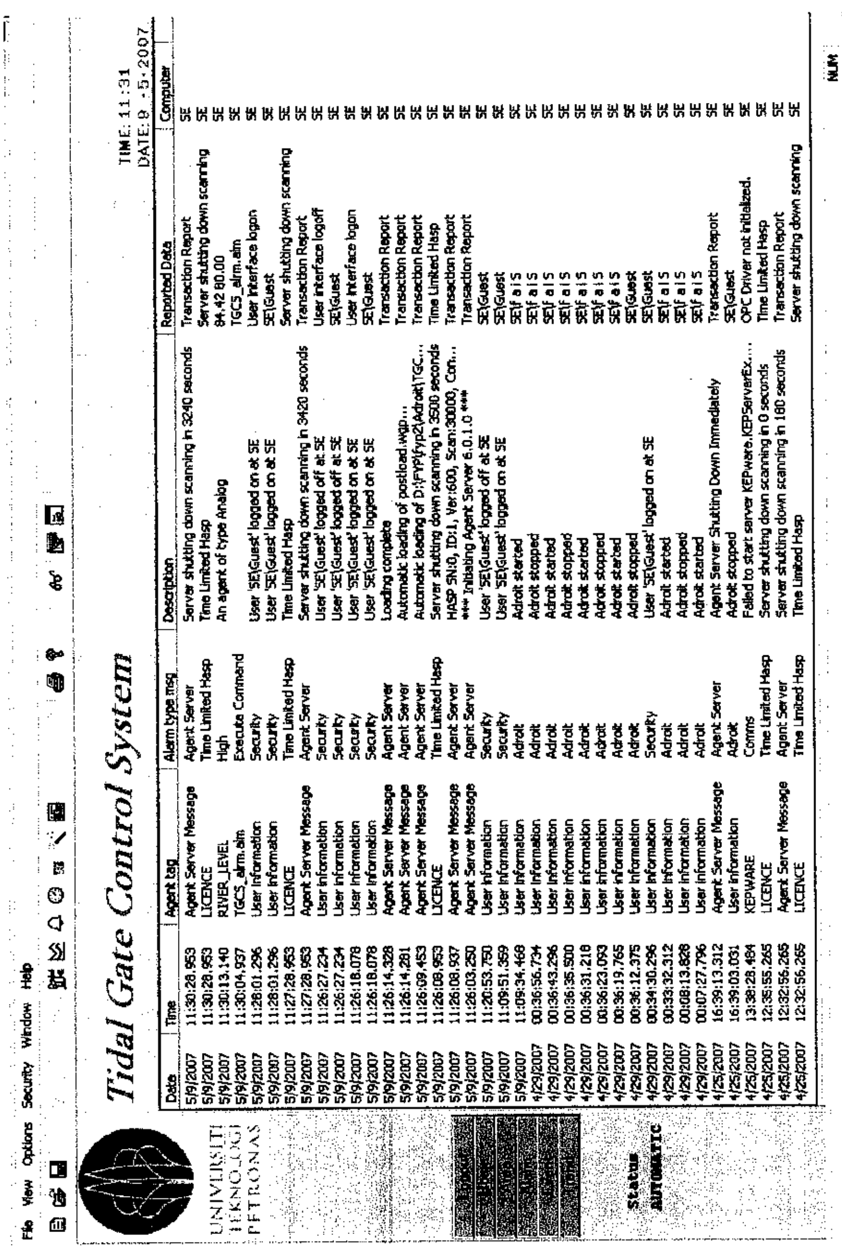
APPENDIX D

FIGURE 4: TGCS SCADA – ALARM WINDOW



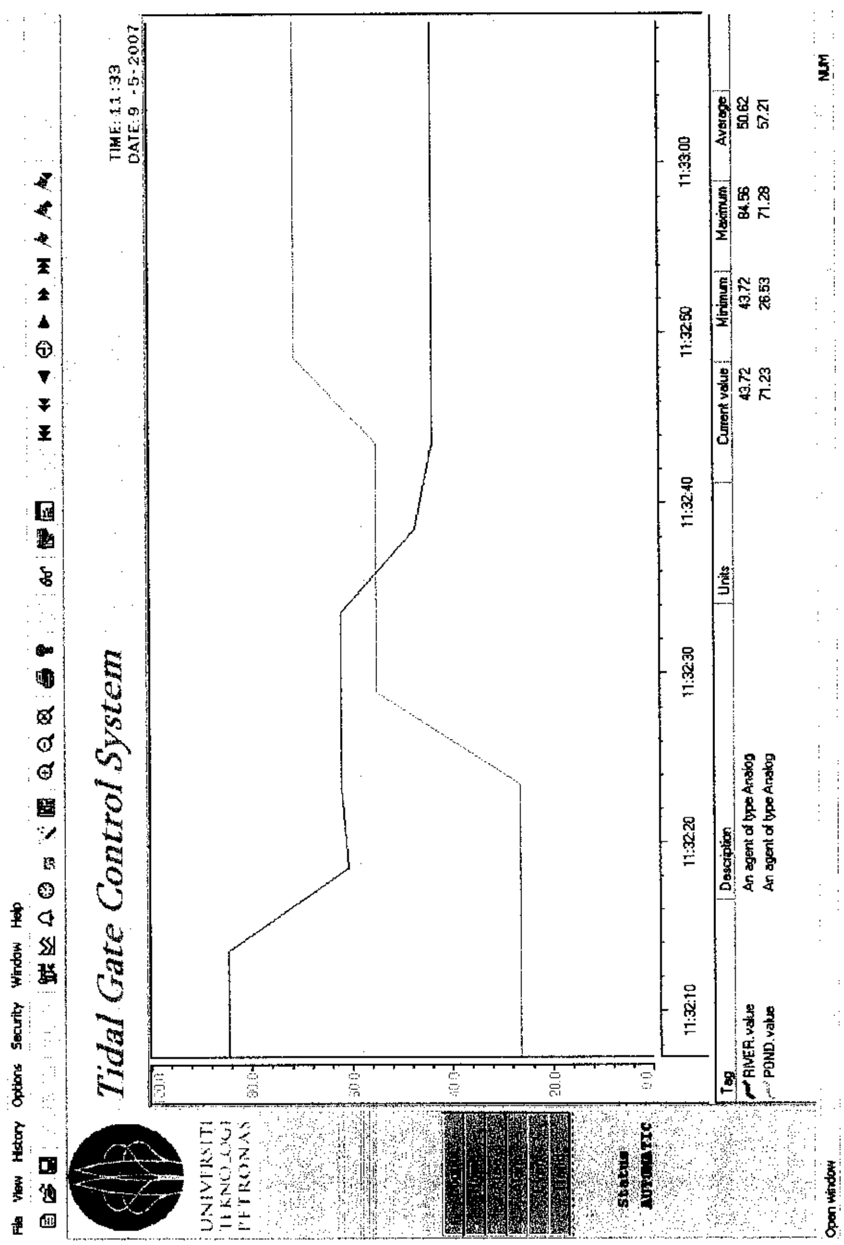
APPENDIX D

FIGURE 5: TGCS SCADA – EVENT WINDOW



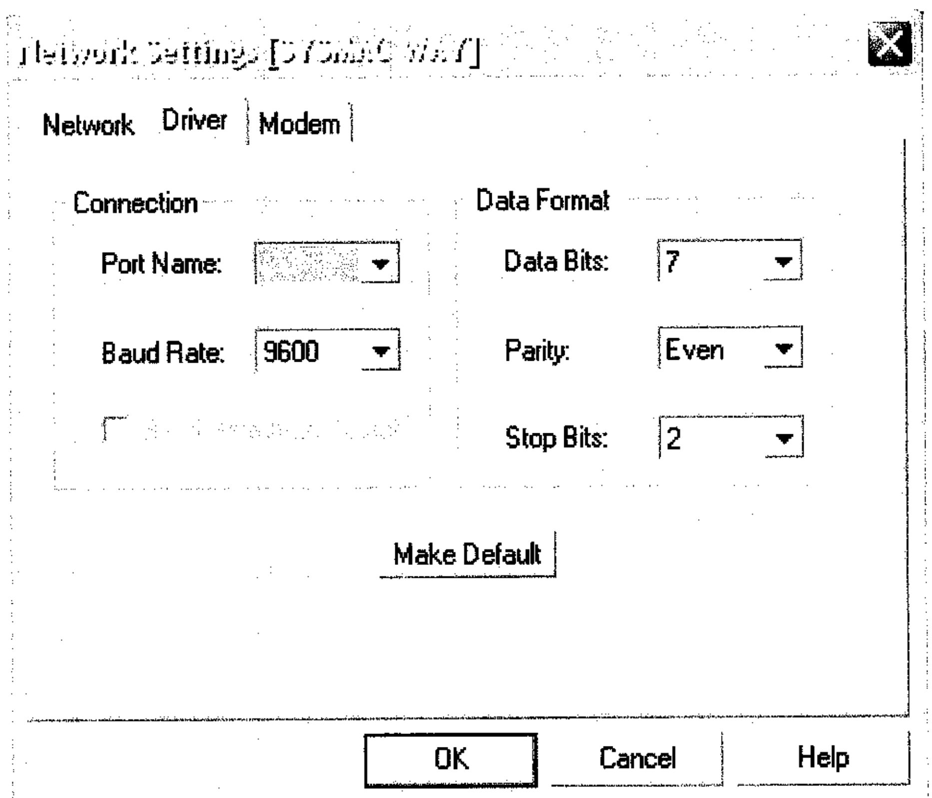
APPENDIX D

FIGURE 6: TGCS SCADA – TREND WINDOW



APPENDIX E

OMRON PLC CQM1H SYSMAC WAY COMMUNICATION SETTINGS



APPENDIX F

KEPWARE ENHANCED OPC/DDE SERVER COMMUNICATION SETTINGS