SCADA Design for Load Management & Smart Energy Management
(Using PLC & HMI)

Authors

Syed Wajahat Ali	12-EE-12
Shahzaib Shahid	12-EE-45
Kashif Afzal Khan	12-EE-132

Supervisor

Engr. Mehroze Iqbal
Lecturer, EED Department

DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY
TAXILA
June 2016

SCADA Design for Load Management & Smart Energy Management (Using PLC & HMI)

Authors

Syed Wajahat Ali 12-EE-12
Shahzaib Shahid 12-EE-45
Kashif Afzal Khan 12-EE-132

A Project submitted in partial fulfillment of the requirements for the degree of

B.Sc. Electrical Engineering

Project Supervisor:

Engr. Mehroze Iqbal

Lecturer, EED Department

External Examiner Signature: ____

Project Supervisor Signature: ____

DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY
TAXILA

June 2016

Abstract

Since the dawn of the Industrial Revolution in the late 19th century, there has been a trend towards ever increasing efficiency and optimization in industrial output. Where steam was the driving force at the outset, today's heavy machinery runs on AC electricity extensively. In the last few decades, the focus has been on making the industrial process streamlined to minimize the use of electricity (and bring down energy costs as a result). One such technique is the use of a central supervisory system to monitor and control industrial units so that they are run in an efficient manner i.e. SCADA. SCADA systems use a PLC (or PLCs) to control and smartly monitor the status of the machines, and present the information to the user and take input from the user using Human Machine Interface (HMI). The HMI can be located either at the PLC's containment cabinet, or at a remote location, and provides a simple and efficient interface between the machines and the user. Special sensory devices are linked to the PLC to achieve data acquisition from the machines. The SCADA system as a whole provides a safe, rapid and efficient mechanism to ensure that the industrial machinery runs optimally.

Keywords:

Programmable Logic Controller (PLC), Supervisory Control and Data Acquisition (SCADA), Human Machine Interface (HMI)

UNDERTAKING

I certify that research work titled "*SCADA Design for Load Management & Smart Energy Management (Using PLC & HMI)*" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Sign:__________

Syed Wajahat Ali

12-EE-12

Sign:___________

Shahzaib Shahid

12-EE-45

Sign:___________

Kashif Afzal Khan

12-EE-132

ACKNOWLEDGEMENTS

Above all, we would like to express our gratitude to Allah Almighty for giving us the strength and courage to undertake this project, and the perseverance to see it through to completion.

Our Project Supervisor, Engr. Mehroze Iqbal, is especially worthy of our gratitude also, since without his guidance and support, it would have been impossible to accomplish such a difficult challenge. He provided us with a lot of opportunities to learn new skills.

We would also like to express our sincere thanks to our sponsors over at Creative Electronics & Automation, who saw the potential in our proposal, and agreed to provide us with logistical support for the assembly of our project. In particular, we are grateful to Mr. Shahzad Muhammad Khan, Director Technical, and Mr. Ammar, Assistant Manager R&D, for their continued assistance and encouragement.

We would also like to take this opportunity to thank all the teacher who have taught us over these past four years, for ultimately preparing us to take on this formidable project.

Lastly, we will say thanks to our families and friends for continuing to support us while we were engrossed in this undertaking.

Table of Contents

List of Figures

List of Tables

Chapter 1 - Introduction

1.1 - Relevant Theory:

1.1.1 - Literature Review

Kamaldeep Kaur Et al. [1] have worked on a system which manages industrial load during peak hours using PLC and a PC based SCADA software. While it is definitely a start towards automatic load management, the PC based interface can pose a risk in that it runs an OS that can be affected by viruses and other glitches. Furthermore, sorting out a problem on a PC is quite complicated. The aim is to replace the PC based SCADA software with a dedicated HMI terminal running specially designed SCADA screens. The advantage of HMI terminals is that they run on simple firmware that is robust, bug free and easily fixable, therefore they are far more reliable than PC based SCADAs.

P. Shunmugakani Et al. [2] have implemented a system which controls various machines via a PLC and SCADA system but with the supervision of a human operator at all times. On the other hand, the proposed system provides this functionality, but goes further than that: it aims to automate the management of industrial loads so that the operator can leave the terminal unattended without any worries and attend to other tasks. In fact, there is no need for a dedicated operator to be present at all - the system, once started and initialized, runs autonomously.

Suresh Kumar Et al. [3] created a Building Management System that was concerned with the safety, security and comfort of the user, providing them with features such as fire hazard protection and presence sensing based lighting. On the other hand, the intended system focuses on the reduction of electricity bills and energy conservation, which are a far more vital concern of industrialists nowadays.

P. Vivekanandan Et al. [4] also developed a SCADA system focused on affordable security in the industry. While this is a necessary requirement, it does not justify a SCADA based system in ordinary Pakistani industries, since the priorities are different. Therefore it was decided to focus on the Load Management and Smart Energy Management aspects of a building management system.

Ming-Yuan & Jung-Chin [5] have proposed a system revolving around fault preventions, operation monitoring and reduction in management costs. Depending on the industry, this could be a viable option, but it would not be justifiable for every industry, especially those with a smaller workforce. On the other hand, a SCADA based Building Management System that keeps electricity consumption in check and ensures optimized office lighting would bring about a tangible reduction in costs for nearly all industries.

To conclude, close to none of the existent SCADA based BMSs that were studied have touched upon automatic Load Management or Smart Energy Management using daylight harvesting. Those that do, fail to meet the standards of robustness and ease of use required by a Pakistani market. However, both of these features are directly relevant to the present scenario in the heavy industrial sector in Pakistan, which is why they are the ones addressed by this project in a manner that is exactly suitable for the average local industrialist.

1.1.2 - What is SCADA?

SCADA (Supervisory Control and Data Acquisition) systems have been around the length of time that there have been control frameworks. Current SCADA frameworks are utilized to screen and control a plant or hardware in commercial enterprises, for example, telecom, substations, power generation plants, water and waste control, vitality, oil and gas refining, private utilities, security businesses and is frequently expected to associate sensors and systems isolated by a huge number of kilometers.

Commands can be sent and information can be acquired from these remote locations through SCADA.SCADA refers to the combination of telemetry and data acquisition. SCADA encompasses the collecting of the information, transferring it back to the central site, carrying out any necessary analysis and control and then displaying that information on a number of operator screens or displays. The required control actions are then conveyed back to the process.

SCADA consists of the following parts which are linked together to make up the system.

One or more field information interface gadgets, normally RTU's or PLC's, which interface to the field sensors.

A communications framework used to exchange information between field information interface gadgets and control units, and the PCs in the SCADA as the central host.

A central host computer server also known as the MTU (Master Terminal Unit).

A single or group of standard HMI (Human Machine Interface) software systems and devices.

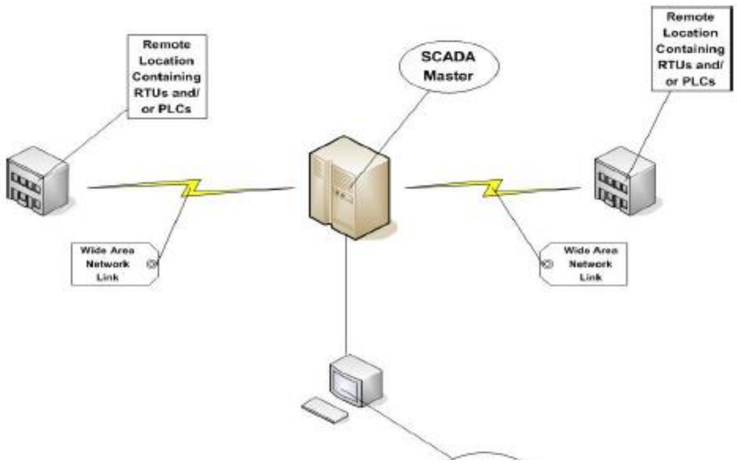


Figure 1. 1 Widely used SCADA system (Communication Technologies, Inc., 2004)

1.1.3 - Types of SCADA

There are different types of SCADA systems that can be considered as SCADA architectures of four different generations:

First Generation: *Monolithic SCADA systems*

Second Generation: *Distributed SCADA systems*

Third Generation: *Networked SCADA systems*

Fourth Generation: *Internet of things technology*

Monolithic or Early SCADA systems:

Mini-computers were used earlier for the SCADA systems. In the early times these systems were developed wherein the common network services were not available. Networks in those times were non-existent and Systems in those times were non-existent and the brought together frameworks remained solitary.

The Wide Area Networks (WANs) were used to communicate with remote terminal units (RTUs) and were designed with a single purpose only and that of communicating with RTUs in the field. The communication protocols used were uniquely developed by the vendors to be used for a specific task of only working with a specific task or supported a single functionality of scanning and controlling points of a specific remote device. The fail-safe for the systems were accomplished by having two systems serving the same purpose, the primary and the secondary system connected at the bus level. The primary function of the backup system was to monitor the primary system and would take over the system if the primary system failed. During this period the backup system would be standing in a stand by position without any processing done.

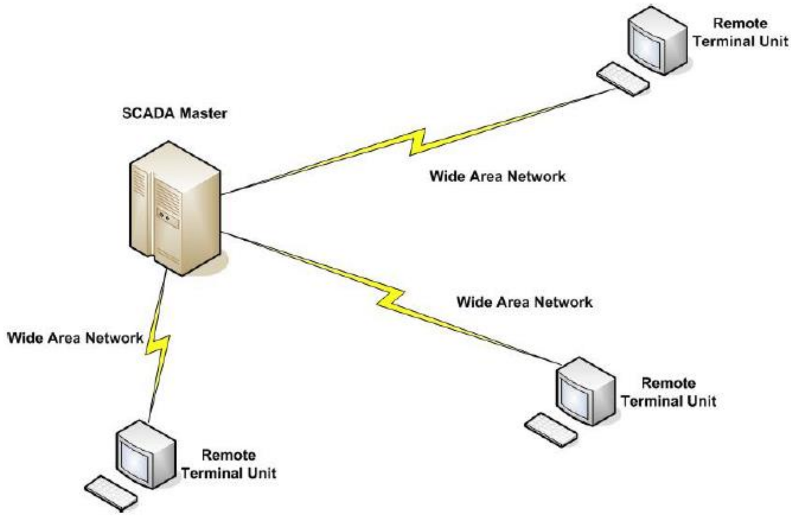


Figure 1. 2 Monolithic SCADA system (Communication Technologies, Inc., 2004)

Distributed SCADA systems:

Advancements in the technologies and the miniaturization of the systems the LAN system to distribute the processing across the multiple systems were used by the next generation SCADA systems. Multiples stations are used in this system, in which each specialized system in its miniature form is connected with each other through LAN and shares information with each other in the real time. These systems are of mini-computer class and are cheap and reliable than their first generation processors. Some of the distributed systems were used as communications servers, used to primarily communicate with the field devices such as RTU's, some were used as operator interfaces such as HMI and some were used to store information or as data servers. These different parts of the SCADA system were linked together through LAN and when linked together acted as large processing units and gave a huge processing power for the system. Due to limitations of the LAN systems the networks had the limits of not reaching out the local environment. The vendors in this system too created its own network protocol rather than using the previous ones. This allowed one to optimize its LAN for the specific task in the real time. But this didn't allow to or limited the connection of different vendors to the SCADA LAN. The distribution of system into parts not only helped in the processing power but also helped to increase the reliability and safety of the system. The failsafe backup systems were not required in this scheme. All the systems are kept in an online state in this model all the time. For an example if any part of the system was to fail, another part could be used to operate the system without the need for shifting from the primary to backup system.

The fails and drawbacks in this model are also like the ones in the first generation, where there are limitations to the hardware and software of the system.

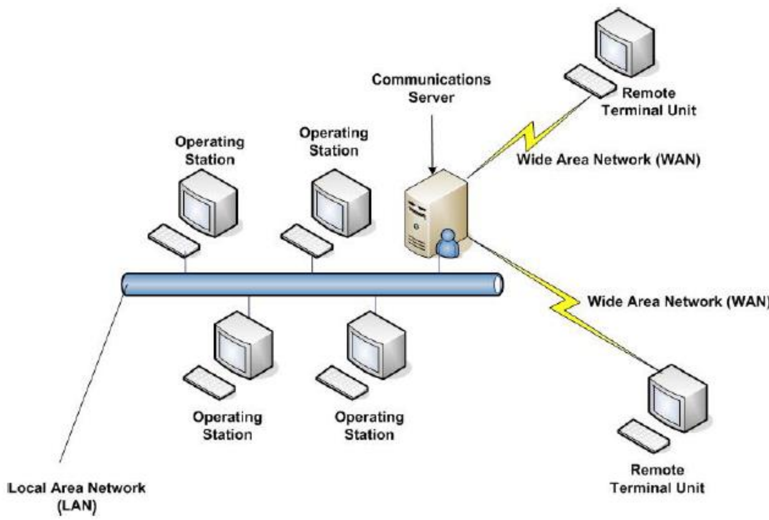


Figure 0.1 Distributed SCADA system (Communication Technologies, Inc., 2004)

Networked SCADA systems:

The current generation of SCADA master station architecture most likely like the second generation system but, with the difference being that of an open source, that means devices or equipment of different companies can be configured together to work as a whole system. There are a number of multiple networked systems at this time too that are sharing master station functions and RTUs utilizing protocols that are vendor-proprietary. The major improvement in the networked SCADA systems is that of opening the system architecture, utilizing of standards that are open to all the vendors and making it possible to distribute SCADA functionality across a WAN and not just a LAN. Open system networks eliminate a number of the limitations that were faced by the previous generations of SCADA systems. This improvement has led to the utilization of off-the-shelf systems that makes it easier to connect third party peripheral devices (such as monitors, printers) to the system and the variety of networks. As the new generations have moved to “open” systems, SCADA vendors have gradually gotten out of the hardware development. This allows SCADA vendors to concentrate their development in an area where they can add specific value to the system–that of SCADA master station software. One of the leading advantages of using SCADA systems comes from the use of WAN protocols such as the Internet Protocol for communication between the master station and communications equipment. This allows the portion of the master station that is responsible for communications with the field devices to be separated from the master station “proper” across a WAN.

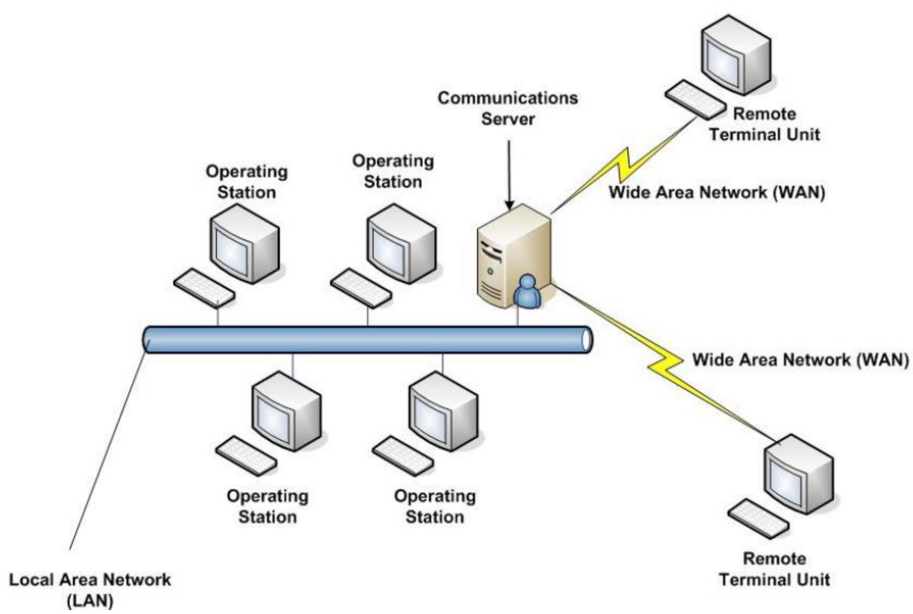


Figure 1. 3 Networked SCADA system (Communication Technologies, Inc., 2004)

Internet of Things SCADA:

The new technologies based on Cloud computing is used for this purpose in which the data of SCADA systems is connected using the internet and database and other information stored over cloud. This technique has helped in reducing the cost of the infrastructure. Adopting this system has helped in the maintenance and integration a very easy to go method. This system includes the real time reporting and helps in computing more complex control algorithms. On the other hand this is a risky in case of security but can be overcome by using the TLS inherent which is manageable and as compared to other protocols much safer (Communication Technologies, Inc., 2004).

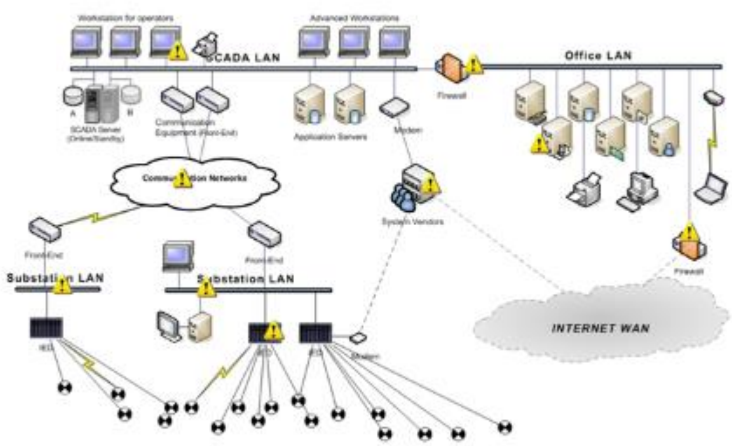


Figure 1. 4 Internet of Things (Communication Technologies, Inc., 2004)

1.1.4 - Key Terms used in SCADA

Handshaking:

It is an exchange of predetermined signals stored in the devices that are sent for the confirmation of the establishment of connection between two devices.

LAN:

Local Area network, for the communication of devices over smaller distances of around 10km. A switching technique is which operates from moderate to high data rate transfers.

Master/Slave:

It is a kind of bus access method in which devices are either marked as master or slave. The slave devices can only transmit data when they are asked to by a master. But the master devices can transmit data all the time.

Port:

It is the place from where the device or network can access. The ports are specific for a specific device or network and can be used to transmit or receive data in the form of analog or digital form.

Protocol:

It is set of conventional commands or instructions that are followed for the formatting and control procedures of the communicating systems. They are used to determine when they are to communicate and at what rate.

RTU:

Relay terminal unit- defined as the remote unit place near the field sensors used to communicate with the master control center that is located at faraway place.

MODBUS:

It is a serial communication protocol used in the present for communicating with interconnected devices. It is used in common for connecting different industrial devices in the SCADA system on the same system network.

Serial:

It is a method of communication in which the data is sent bit by bit, sequentially over a communication channel.

RS-232 DB9:

It is one of the popular way of connecting and communication of data acquisition devices such as an example HMI with computers. The DB9 cable consists of 9 pin connector used for the communication.

RTS:

Request to send

DTR:

Data terminal Ready

Baud Rate:

The communication between the devices can be done at a number of rates and the rate of information passing through the devices is known as the baud rate which has to be matched when communicating with different devices. For example some devices work at 9600 baud rate.

DCS:

Distributed control systems- It is a process oriented system that doesn't depend on the circumstances. This system does a local control over the system.

PLC:

The PLC as a unit contains a processor to execute the control activity on the field information given by input and outputs of the device.

Sensors:

Devices used to extract data from the environment and send it to the desired RTU or PLC for analysis. Today's sensors are intelligent and consist of information storing and send facilities.

SCADA server:

It can be any kind of a server, for e.g. a Web server which is used for data logging, analyzing data, server the client through a firewall and can make real time decisions.

Station Address:

Every RTU, PLC, Devices or a station must have a unique address.

Error Detection:

The error detection in communication is very important as it checks whether the information sent is the same as the information received. This is done using a number of methods such as CRC (Cyclic Redundancy check) method.

1.1.5 - SCADA Hardware Description

SCADA hardware consists of many devices which can be interconnected to make up the whole system. These devices can be from different vendors as in today's date the networked SCADA type has the advantage of being able to connect and communicate with different vendor's devices. Some of the vendor's of today that provide the hardware for SCADA systems are Rock Well Allen Bradley, General Electric, Emerson, Schneider Electric.

PLC:

A PLC consists of Central Processing Unit (CPU) containing an application program and Input and Output Interface modules, which is directly connected to the field I/O devices. The program controls the PLC so that when an input signal from an input device turns ON, the appropriate response is made. The response normally involves turning ON an output signal to some sort of output device. PLCs also support communication over various standard protocols such as RS-232 and RS-485, Ethernet etc. The RS-232 protocol is used in this SCADA system to acquire data from the smart energy meter and sensor, and to communicate with the HMI. For the smart energy meter, the structure of the communication follows the industry standard Modbus RTU protocol. The PLC is commonly regarded as the heart of the control system. With a control application program (stored within the PLC memory) in execution, the PLC constantly monitors the state of the system through the field input devices' feedback signal. It will then use program logic to determine the course of action to be carried out at the field output devices.

HMI:

A human–machine interface (HMI) is the input-output device through which the human operator controls the process, and which presents process data to a human operator. HMI (Human Machine interface) is usually linked to the SCADA system's databases, configuration, management, statuses and trends. It is connected to the PLC and constantly communicates with it. The HMI enables the operator to control the SCADA system manually, and view the present status of the devices which fall inside the SCADA system. The HMI shows visual and graphical representation of the system and the devices used in the system. For e.g. the HMI can show a visual aspect of the substation, the transformers, the breakers, tie-lines.

The HMI device choice for this SCADA system has been left open, since it is best to choose it after the finalizing of other aspects of the SCADA. Simplistic HMIs are suitable for smaller SCADAs whereas a sophisticated HMI unit may be required for a more complex control system. HMI's can be programmed through specific software provided by the vendor.

Field Instruments:

Control of any systems requires to have an information required for that purpose, without which the system is blind, so like a human body the sensors in the SCADA system also known as the field instrument acts as the ears and eyes of the system. Instrumentation is the main important aspect of any system for its safety, optimization and control. Along with the sensors the actuators also come under the tree of field instruments which are used to control the output or mechanism of any system.

Then sensors and the actuators communicate with the PLC or an RTU through different communication protocols and share information and receive commands to perform a particular operation. The information received from the sensors is processed by the PLC or an RTU and then the required operation command is sent to the actuators to perform a specific action (Schneider Electric Telemetry and Remote SCADA solutions, 2012).

Today’s instruments are advanced and much more intelligent than their primitive ancestors. They can store data and communicate it through different ways to the processor unit. Although today's instrumentation specialist requires more specialized learning also, the capacity to outline, introduce and look after devices, than before, this is relieved by the decreased expense in computerizing forms and higher specialized abilities held by work force. The instruments should also have the ability to withstand extreme environmental conditions. They must also comply with the standard of withstanding the EMC (Electro Magnetic compatibility).

RTU:

RTU (Remote Terminal Unit), as the name implies is some kind of a device placed at a far-away location for communicating and affecting some other device placed at a remote position. It is a stand-alone data acquisition and control device, that receives data from the remote devices, consists of a microprocessor to process the information received, evaluate and analyze the data and then send a command signal to another device placed in the remote position for some specific operation. It can be configured and programmed for different tasks and operations through some master central station. Mostly RTU communicate back the information received to some master station, but RTU's can also communicate with other RTU's on a peer-to-peer basis, where each RTU sends and receives information to each other.

RTU's come in different sizes and the size difference only differs the number of input, output, digital, analog, communication port sizes. Small sized RTU's less than 10 analog and 20 digital signal pins, where-as the medium sized have more than 100 digital pins and 40 analog pins. RTU modules consist of some of the following parts:

Control Processor and its memory

- Analog inputs
- Digital inputs
- Analog outputs
- Digital outputs
- Power supply
- Communication channel
- Counter inputs

Remote Communication Networks:

The remote correspondence system is important to hand-off information from remote RTU/PLCs, which are out in the field or along the pipeline, to the SCADA host situated at the field office or a master central control system. SCADA system can be over a vast area linking different areas and a number of networks, or communicating information to a master station. This linking of information is crucial for the system and has to be timely without which the operations won't take place accurately and efficiently. In the early time of the SCADA systems the communication process was fulfilled by leasing lines or using the dial up modems. This process was slow and time consuming with a lot of expenses for installing and maintenance. But recently, the communications systems have been shifted to radio or satellite communication. Different philosophies of communication are used for the information exchange. There are basically three types of communication philosophies.

Point to Point Communication:

The data is communicated between the two stations in this form of communication. Either of the stations can be signed as a master or a slave and information shared among them. Both the stations the master and the slave can communicate in a duplex mode where in transmitting and receiving is done on two different frequencies or simplex method.

Multipoint communication method:

A single master and multiple slaves are connected in this scheme which communicate with each other. The slaves communicate with the master and if the slaves want to communicate with each other than they have to communicate through the master which acts as the mediator. The peer to peer communication can take place between the slaves and the collusion of data between the two, if the devices want to communicate at the same time collision would occur, this can be prevented trough complex protocols.

Relay station method:

One of the methods is the store and forward relay operation in which the message is transmitted to the store and forward terminal from the master station and then the information is relayed on the same frequency as it is received to different RTU’s. This method requires the data to be sent two times but is useful as it saves the cost and heights.

Second method is the talk through repeaters. In this the range of the system is increased by using a repeater which receives the signal at one frequency and sends it at a different frequency. This means that the devices have to receive at one frequency and transmit at the opposite frequency for communication. The communication is done between all the devices through a single repeater, and the mast have to be placed at a geographical height so that it can communicate with all the devices. The drawback is that if the repeater collapses the whole system collapse.

Supervisory system:

The systems used for communication between the devices of the SCADA system such as sensors, RTU’s PLC’s, HMI and the software used for the HMI’s in the control center workstations. Master station comprises of a single PC or HMI in small scale SCADA systems used for smaller industries, where-as larger SCADA systems consist of a large number of workstations and redundant hot standby devices for emergency. The data can be acquired, processed and analyzed using the supervisory system.

1.1.6 - SCADA Software Description

SCADA software is very important, and its requirements are specific to every plant. But in general the SCADA package should show high performance and be of great efficiency to the specific plant. Along with being efficient and giving high performance it should be easy to upgrade and handle any further requirements in the near and long term future. SCADA software should be expandable and easily modifiable as the technology grows. SCADA designs can be divided into two categories.

1. Centralized

2. Distributed

Centralized system is used where a small plant or industry can be controlled using a single computer and mainframe. All plant's information and data from devices is stored on one mainframe server. But there are disadvantages to this system as the SCADA system becomes expensive for small scale industries and initial cost is very high for a small growing industry. The scheme of increasing the SCADA hardware and upgrading is not possible as the size has been fixed earlier. The redundancy scheme as a fail-safe is also impossible as the entire system has to be imaged. The need of skillful labor also increases the cost of the system, not appreciable for small industries.

Distributed system of SCADA software is used for large scale industries where large number of PC's share information with each other. The problems faced here are:

The difficulties faced in configuring different computers together. Duplication of systems which reduces the efficiency. And the difficulty in making the priority approach for the systems, that which system's request must be prioritized if different interfaces require the same information from a device at the same time.

There are a number of tasks that are performed by the SCADA software and each task has its own processing:

- Input /Output: The plant or industry is connected along with the control system and the monitoring system.
- Alarm system: This program manages all the types of alarms by checking the digital alarm areas and comparing the values to the predetermined threshold values of the alarms.

- Reports: Plant data is collected and its information printed in the report form on the screen. Reports can be made in the periodic order or any event can trigger the report.
- Display: The operations that are to be monitored are continuously displayed on the screen along with the tasks that have to be controlled by the user.

Some other Software Technologies:

Ladder Logic:

A PLC has many “input” terminals, through which it interprets “high” and “low” logical states from sensors and switches. It also has many output terminals, through which it outputs “high” and “low” signals to power lights, solenoids, contactors, small motors, and other devices lending themselves to on/off control. Ladder Logic programming for PLC differs from conventional sequential languages such as C++ in that all instructions are executed simultaneously rather than sequentially. Various design environments are available, including some proprietary ones provided by PLC manufacturers directly.

HMI Interface Designer:

A special design software, provided by the manufacturer of the HMI, is used to create the screens of the HMI unit which will serve as the interface between the user and the system.

1.2 - Project Overview

1.2.1 Application of SCADA for Industrial Load/ Energy Management

Load Management

Two heavy AC loads (in the KW range) are used to demonstrate the Load Management aspect of the SCADA system. The PLC is instructed to maintain a desired net power consumption of the industrial complex at all times. It acquires this power consumption through a Smart Energy Meter which in turn is connected to 3 phase instrument transformers.

After acquiring the net power consumption value, the PLC checks this against a user specified threshold. If the net power consumption exceeds the threshold for a user specified time interval, it turns off Load 1 to bring the net power consumption down. If the power consumption is still higher than the threshold for a user specified interval, it turns off Load 2.

Once the system's net power consumption becomes lower than the user specified threshold by a specific amount the PLC turns on Load 1. If the power consumption goes even lower, while Load 1 is on, the PLC will turn on Load 2 as well. 7

The status of both loads will be relayed to the operator on the HMI, and an alarm will be sounded if the either load is turned off. The breakers for both relays will give feedback.

Energy Management:

Several LED lights controlled by ballast are used to implement the Daylight Harvesting Smart Energy Management feature. The PLC acquires the site's light intensity levels using a Light Sensor, and controls the brightness of the LED lights by sending a 0-to-10V analog signal to the desired ballast.

If the current light intensity is outside the user specified range, the 0-to-10V signal to the ballast is varied to proportionally vary the brightness of the LED lighting. In a 0-to-10V scheme, 0 means that the ballast operates the light at minimum intensity, and 10V means that the ballast operates the light at maximum intensity.

A typical example is as follows: During daytime, there may be sufficient sunlight such that there is no or little requirement for LED lighting to maintain the user specified light intensity. Corresponding to this, the PLC will adjust the analog voltage control of the ballast to ensure that the LEDs run on little brightness. In other words, sunlight and ambient light is utilized to the maximum extent and LEDs are relied upon as little as possible.

1.2.2 - Comparison with existing solutions

The solutions that were used previously, before the implementation of SCADA systems and the one's that are used alternatively in contrary to the SCADA are the manual ways of control and analysis. Readings are taken manually from the sensors and compared with some base value and the control is applied manually with the man power. The man power required for these solutions is very high and need to be present all the times close to the system. This process requires the utmost attention of the workers and is not efficient process with a lot of errors. The errors in this process are due to the lag in the extraction, analysis of data and then the required control is applied to the system which consumes a lot of time. This process is slow and may not function properly as if the person may be late in implementing the required procedure for this process. E.g. SCADA system used for controlling a substation if it was replace with conventional solution would require more labor and inefficiency. If the substation is GIS substation and the breaker gas of the bus bar insulation gas is leaked and the breaker doesn't trip, for each breaker the engineer has to check the gas pressure separately and according trip the breakers if the pressure is not to the required value. But in the SCADA system the sensors are connected to the RTU and can be analyzed and controlled by the user from the master station and don't need to come to substation for the required work. On the other hand the same thing can be applied for the synching of frequency for the two bus bars. The SCADA system has helped in many ways where many stations have become unmanned and don't require large labor force for a single task.

1.2.3 - Framework required for a Basic SCADA

SCADA systems is the future and the most worked on technology of today where it is used to control the devices and assets which are scattered and the acquisition of data from centralized stations is important. These systems are used for power systems such as substations, water distribution, chemical industry, security, oil and gas refineries, distribution systems and as well as in transportation systems. A number of outputs and inputs are processed by the centralized system which is connected to a variety of data transmission systems and the HMI's provide a visual and graphic display to the user.

SCADA systems collect information from the sensors placed in the field and transfer the data collected to the master station where the information is analyzed, compared and then the rightful commands are sent to the actuators or any other devices. The control can either be automatic or it may be performed by manual operator and this depends on the sophistication of the system.

Both hardware and software are affiliated with the SCADA architecture. Hardware typically used for the SCADA system is MTU present at the master control center. The information is communicated between the hardware through the communication equipment such as radio, satellite, Ethernet. The information can be extracted from the sensors but to implement the commands by the MTU, some other devices are present which are known to be RTU's. In today's date PLC also acts as an RTU and controls the actuators and sensors placed in the field for specific purposes. The MTU works on the information provided by the RTU and PLC and the sensors while the communication is done between the devices by the communication hardware. The software present for the SCADA determines when to send the information to a particular device and when to monitor something from the sensors. So the software is the gateway and it can initiate any particular values.

IED's are known as the Intelligent Electronic devices and are capable of interacting directly with the Master control center without any intermediate such as RTU or PLC. The MTU can directly give commands to the IED which can operate on its own. The IED's may poll with other IED's to communicate with the MTU and are connected directly to the control and monitor process.

As can be seen in the figure given below, a basic structure of SCADA system is shown with all its components. The Control center or the Master Control consists of an MTU and the communication devices. The Control center also consists of the devices able to interact with the user and get information from the user for processing known as HMI and the historical serves for securing information for safe keeping. Logging of information, analysis and error detections with all the kinds of alarms are present in the control center. Special protocols and serial communication methods are developed for the communication of data over cables or satellite.

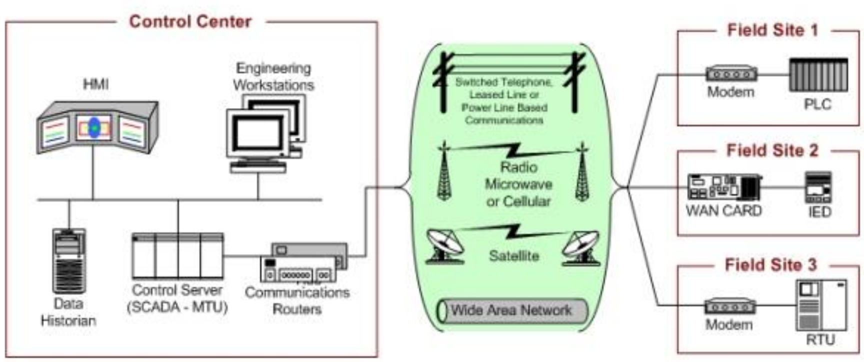


Figure 1. 5 General Layout for Basic SCADA system (Keith Stouffer, 2006)

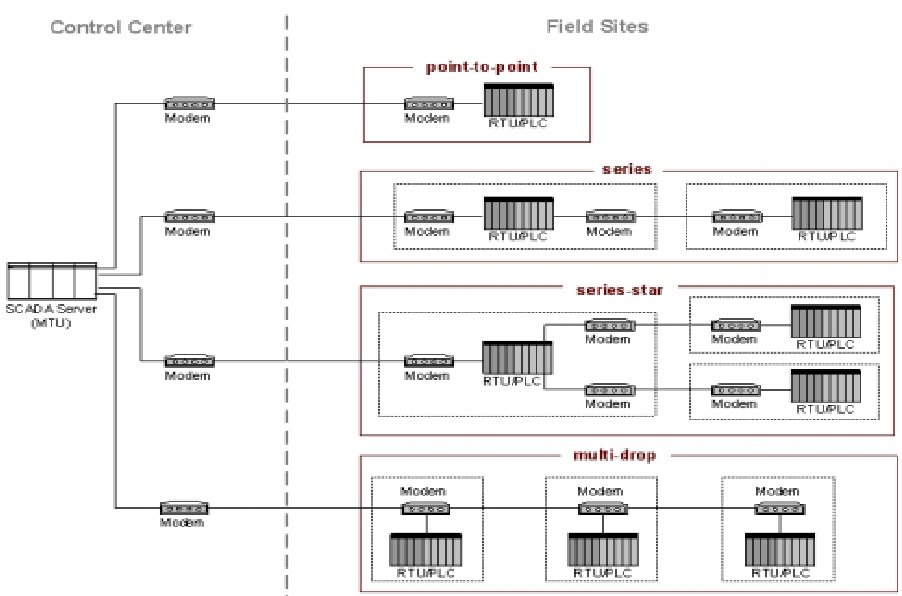


Figure 1. 6 Basic SCADA communication Topolgy (Keith Stouffer, 2006)

1.2.4 - Core Functionalities of the Project

Industrial Load Management:

If the load is greater than the required limit set by the user than some important measures are taken to prevent it from overloading that is the machines are shut down priority wise. The fixed load or the load important to the industry is allowed to work all the time but the loads secondary to the industry are shut down priority wise. As the loads drop and come to the threshold value no further loads are shut down. The PLC is programmed in such a way to give the upper and lower limit to the threshold load because if the load varies in a very minute amount and doesn’t come below the required value than the system would go into a zone where the loads would shut down and start again over and over again. These load fluctuations are displayed to the user as well as notified on HMI with the alarm which is triggered when the load exceeds the desired limit.

This figure illustrates the Load Management procedure of the SCADA system:

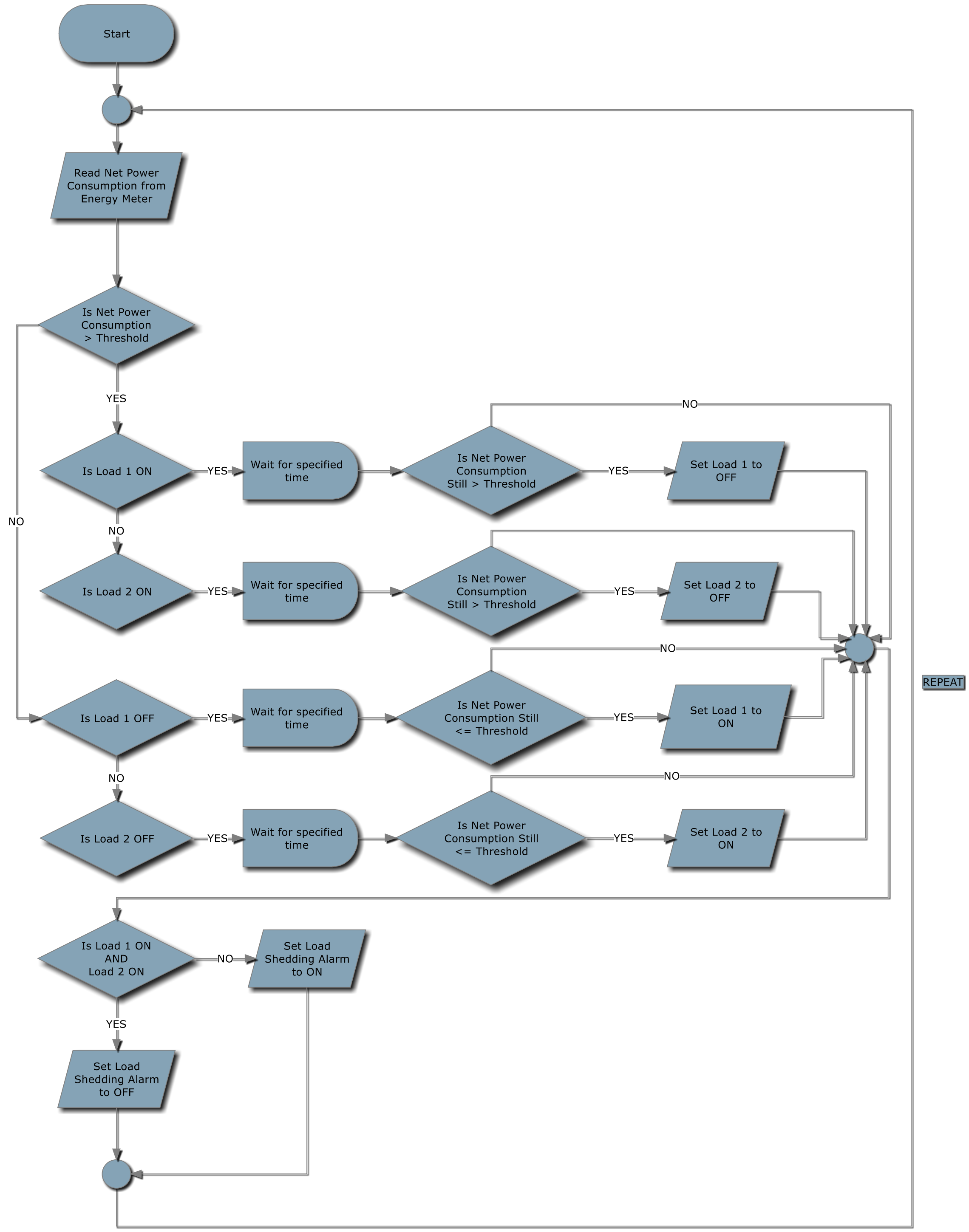


Figure 1. 7 Load Management Flowchart

Under and Over Frequency Protection

The frequency of our electrical system in Pakistan is not much stable and can cause disastrous problems. One of the problem is that the machines would not work properly on frequencies other than the required frequency or the speeds of the machines would vary with frequency along with the characteristics of the machine. Change in speed of the machine can cause loss of functionality of the machine and its purpose, for example the conveyer belt carrying bottles to be filled in an industry, if the speed varies the bottles won’t come to the exact positon and this would cause loss for the industry. Frequency on the other hand can damage various other devices which should be kept under notice, for this purpose the frequency of the system is kept under check and if varies from the desired value should trigger the relay to operate thus shutting down the whole system. The under and over frequency fluctuations shut down the whole industrial system as well as an alarm is triggered which shows the shutdown of the system.

Smart Energy Management system:

Work in progress for further upgrading of the system in the future.

Chapter 2 – Project Implementation

2.1 - Hardware Research & Selection

2.1.1 – Master Terminal Unit

Since ours was decided to be a basic SCADA system, handling only two processes i.e. those of Load Management and Smart Energy Management, a single PLC device was deemed to be the best fit for the MTU.

After trying out the Omron CP1-E initially, and then the **Fatek FBs-40MC**, the latter was chosen for the simplicity of its development environment, and the accessibility of its features for beginners. The CP1-E is a worthy candidate for more advanced applications requiring precise ladder logic coding.

Here are the technical specifications of the Fatek FBs-40MC Programmable Logic Controller:

24 points 24VDC digital input (6 points high speed 200KHz, 2 points medium speed 20KHz, 8 points medium speed total 5KHz); 16 points relay or transistor output (6 points high speed 200KHz, 2 points medium speed 20KHz); 1 RS232 or USB port (expandable up to 5); built-in RTC; detachable terminal block

Figure 2 1 Specifications of FBs 40MC PLC (FATEK AUTOMATION CORP, n.d.)

The base PLC was augmented with a **Fatek CM-25E** communication module to allow for communication over Ethernet, RS-485 and RS-232 protocols, with RTU(s) and HMI, as well as for uploading ladder logic programs and configuration parameters to the device itself.

Here are the technical specifications of the Fatek FBs-CM25E communication module:

1 port RS232 (Port3) + 1 port RS485 (port 4) + Ethernet network interface communication module

Figure 2 2 Specifications of FBs CM25E module (FATEK AUTOMATION CORP, n.d.)

For the Smart Energy Management portion, analog communication would be required, for which the **Fatek FBs-B2A1D** AIO board was installed in the PLC's expansion card slot.

Here are the technical specifications of the Fatek FBs-B2A1D Analog Input / Output board:

2 channels, 12-bit analog input + 1 channel, 12-bit analog output combo analog board (0~10V or 0~20mA)

Figure 2 3 Specifications of the FBs B2A1D board (FATEK AUTOMATION CORP, n.d.)

2.1.2 – Remote Telemetering Units

For the Load Management part of the project, we required a 3 Phase Energy Meter to measure the overall power consumption of the industry, and relay it back to the Master Terminal Unit for further processing.

A further requirement was to measure other power quality parameters such as frequency, power factor and real and reactive powers separately.

The **KMB SML 133 Smart Energy Meter** was chosen to this end. It comes in several variations, based on the kind of input it takes and the format in which it relays its data.

We opted for the variation that took Line-to-Neutral voltages from three phases directly, and Line currents by means of X/5A CTs.

Here are the technical specifications of the KMB SML 133 Smart Energy Meter (KMB systems s.r.o., n.d.)*:*

- measuring multimeter of actual network data
- 4 or 6 quadrant, three-phase energy meter (kWh, kvarh)
- alternatively registers apparent energy also in kVAh (bivector electricity meter funtion)
- pulse outputs and programmable alarm relays (option RR, RI, II)
- single-phase, three-phase or Aron connection
- direct & indirect voltage and current connection (can specify VT and CT ratio)
- precise continuous measurement, 128 samples/period, independent 6.4 kHz sampling
- voltage and current: class 0.5 / 0.2 according to 61557-12
- energy: active 0.5, reactive class 1 according to 61557-12, 62053-22 resp. -23
- built-in temperature sensor, binary input (state or pulse)
- optional remote RS 485 or 10/100Mbit RJ45 Ethernet communication
- optional inputs for special split core and throughole CTs (option P and S)

Figure 2 4 Specifications of the KMB SML 133 meter (KMB systems s.r.o., n.d.)

For the Smart Energy Management part, an Ambient Light Sensor unit was required which could measure the light intensity in the field and prove analog feedback to the MTU.

Two candidates were selected for this purpose:

Kele MAS Series

MASI-12X0T (indoor ambient light sensor) atrium light sensor unit 500 FC 10 minute time response

MAS-CAL (field calibration unit)

Generic Ambient Light Sensor

4-20mA 20,000 Lux

The generic ambient light sensor was selected ultimately, since the Kele solution’s cost went above $2,000, which was unfeasible for the project in its prototype phase. The generic ambient light sensor on the other hand, would cost us <$100, and serve well as an initial testing device.

2.1.3 – Human Machine Interface

Since the system to be designed would be used by field operators with minimal knowledge of advanced controls, it was decided that a simple keypad based HMI would fit the bill.

The Beijer Electronics Hitech PWS-6300S HMI was chosen for this. Its design interface allows easy interfacing with a number of PLCs from different manufacturers, including Fatek/Facon FBs series devices, which was a further benefit.

Here are the technical specifications of the Beijer Electronics Hitech PWS-6300S Human Machine Interface:

Item	PWS6300S
Display Type	Mono STN LCD
Display Color	Black / White; 16 gray levels
Display Size	3.0" (diagonal); display area is 65x35mm
Number of Pixels	160x80; could display 20x10 characters of 8x8 size
Contrast Adjustment	Contrast adjustable by VR on the back
Back Light	Yellow-Green LED; Life time is approx. 50,000 hours
Keypad	16 mechanical switches
Input Power	24VDC±15% (or 20V-28V); Under 8 W

Flash ROM	4M bytes
RAM	128K bytes
CPU	32 bits RISC
Battery Backed Memory	X
RTC	Yes
Communication Ports	RS232/RS422/RS485
Front Panel Seal	IP65
Ambient Temperature	0~50°C
Storage Temperature	-10~60°C
Ambient Humidity	20-90% RH (non-condensing)
Vibration Endurance	0.5mm displacement, 10-55Hz, 2 hours per X, Y, and Z-axis directions
Shock Endurance	10G, 11ms three times in each direction of X, Y, and Z axes
RF Emissions	CISPR 22, Class A
CE	EN61000-6-4,EN61000-6-2

External Dimensions (mm)	173.0(W) x 105.5(H) x 51.79(D)
Cut-out Dimensions (mm)	160.8 x 93.3
Weight	0.65 Kg
Cooling	Natural cooling

Table 2 1 Specifications of the HITECH PWS 6300S HMI (Beijer Electronics, n.d.)

2.1.4 – Communication Media

- Between MTU and RTU:

  Communication between the KMB SML 133 Smart Energy Meter and the Fatek FBs-40MC PLC was done over the RS-485 serial protocol. The meter natively supported this protocol, whereas support was added to the PLC by means of the CM-25E communication module.

  The RS-485 connectors / ports have three pins / terminals – Data (B) +, Data (A) -, and GND.

PLC Side	Meter Side
Data (A) -	Data (A) -
Data (B) +	Data (B) +

GND	GND

Table 2 2 PLC to Energy Meter Serial config

- Between MTU and HMI:

  Communication between the Fatek FBs-40MC PLC and the Beijer Electronics Hitech PWS-6300S HMI was done over the RS-232 serial protocol. The HMI natively supported this protocol, whereas support was added to the PLC by means of the CM-25E communication module.

  The configuration is as shown:

PLC Side (male)	**HMI Side (male)**
Pin 2	Pin 2
Pin 3	Pin 3
Pin 5	Pin 5

Table 2 3 PLC to HMI serial config

- Between MTU and PC:

  Communication between the Fatek FBs-40M PLC and the PC was done over the RS-232 protocol. The laptop PC used for programming and configuring the device had an RS-232 male port built into it, while the PLC had a female port via the CM-25E module. Therefore, a male-to-male RS-232 connector cable was required, with both of its ends terminating in female connectors.

The configuration is as shown:

PLC Side (female)	PC Side (male)
Pin 2	Pin 2
Pin 3	Pin 3
Pin 5	Pin 5
Pin 7 to Pin 8	Pin 7 to Pin 8

Table 2 4 PLC to PC serial config

- Between MTU and Analog Light Sensor:

  The Fatek FBs-B2A1D AIO board allows for straightforward analog communication between the PLC and the Ambient Light Sensor. A 4-20mA current loop provides the feedback to the PLC, where an on-board ADC converts the raw input to digital information stored in special registers.

2.1.5 – Simulated Loads

It wouldn’t be possible to directly hook up the designed SCADA system to the industrial load – which is why, in order to test that the SCADA system was fully functional, we decided to use scaled down models for the industrial load, slaved to the PLC outputs.

These scaled down models were simply several **100W tungsten filament lamps** which would provide a maximum power draw of 700W. A couple of these lamps would be connected to relays that would be driven by PLC outputs – hence simulating the automatic Load Management portion of the project. Note that these lamps are just models for loads – in actuality, these loads could be air conditions, induction motors, vent fans and so on.

For the Smart Energy Management portion, the **DIML6A driver by USAI Lighting** was a worthy candidate. It can be operated by a 0-10V analog output that can be obtained from the FBs-B2A1D and can drive an LED lamp slaved to it. Even better, the live and neutral connections to the driver can be relayed externally, giving our SCADA system the ability to externally cut off power to the lighting in case of an emergency.

2.1.6 – DC Power Supply

Since the inputs (from multi-state switches) and outputs (to relays) would be 24V DC based, and the HMI would also run on 24DC, it was decided that an external dedicated DC power supply would be a wise investment for the prototype.

While the PLC has its own internal 24DC output, we did not want to load it excessively.

2.1.8 – 100/5A CT

As a result of the limitation of the environment in which we were expected to demonstrate the project, we were only given access to a single phase from the main power supply, which is why the meter only required a single phase for operation.

This in turn, only required us to select a single CT suitable to couple with a single one of the meter's current inputs. A 100/5A CT ratio was deemed reasonably sensitive to the changes in load we wished to monitor and control our process with.

2.1.7 – Miscellaneous

3x Omron Relays

4x Omron Circuit Breakers

1x Multi-State Input Switch

2.2 – Software Research & Selection

2.2.1 – PLC Programming Environment

As per the recommendation of the PLC manufacturer i.e. Fatek, the **WinProLadder** programming environment was selected for programming the PLC.

WinProLadder allows the engineer to specify the functionality of the PLC in the specific application using LadderLogic and has many functions to make the control of common industrial processes easier e.g. advanced PID functionality.

Furthermore, it natively supports the Modbus protocol for communication between intelligent devices from different manufacturers. Modbus is the de facto industrial communication protocol developed by Modicon (now Schneider-Electric) (Modbus Organization, Inc, n.d.), and is used extensively in this project to enable values to be read from the RTU Energy Meter by the MTU PLC.

2.2.2 – HMI Screen Design Environment

As provided by the HMI manufacturer, Beijer Electronics, the **ADP6** design environment was used to design and configure the Hitech PWS-6300S HMI screen.

This advanced designed environment has dozens of advanced input options, such as numeric, push button and static button, and output options, such as meters, graphs and alarms, to allow the engineer to develop a screen befitting a SCADA system, with fluidity and full control in a drag-and-drop manner.

Furthermore, it natively supports communication with the Fatek/Facon FBs series of devices, thereby eliminating the need to go into deep configuration to make serial communication over the RS-232 possible.

2.2.3 – Communication Testing Utilities

Before the RTU and the MTU could be successfully conducted over the RS-485 Modbus protocol, both devices had to be tested individually to verify that their Modbus communication functionality was in perfect working order.

The WinProLadder environment made this possible directly in case of the MTU PLC.

But for the RTU Energy Meter, a third-party tool by the name of Simply Modbus Master was employed. This tool allows the engineer to send Modbus commands over the chosen protocol to the device connected to the designer PC.

Furthermore, it allows for in-depth analysis of the response from the slave device, which is very useful for identifying the exact nature of the error in communication, in case it occurs.

We utilized its free trial version, which allows for a limited number of commands to be sent via the utility, since this was more than sufficient for our testing and troubleshooting purposes.

2.3 – Software & Hardware Integration

2.3.1 – Power Supply & Circuit Breaker / Relay Configuration

Each component of the SCADA system had to be provided with its own power supply; to ensure that this was done in a safe manner. To this end, each device was connected to AC Power via a

220VAC circuit breaker. This ensured that power could safely be removed in the event of an emergency, and also allowed us to test individual parts of the SCADA system independently.

i) PLC: Power had to be supplied to its Live and Neutral Pins for the device to operate correctly, which was done by means of a separate circuit breaker.

ii) DC Power Supply: A 24VDC/2A power supply was required for the HMI and PLC digital inputs to function. This DC power supply was fed AC line power which it rectified and regulated up to 24DC; the AC supply was provided via an independent circuit breaker.

iii) HMI: The HMI ran on 24 VDC, provided via the DC Power Supply.

iv) PLC Digital Input / Output Supply: The 24V positive and negative connections were given to the V+ and V- inputs of the PLC, and V- was specified as common for the PLC inputs by connecting the S/S terminal of the PLC to V- as well. Each desired input terminal $X_{0,}$ X_1, X_2, of the PLC was connected to V+ by means of a multi-state switch. By changing the state of the switch, the status of the inputs could be altered, resulting in changed functionality of the PLC through Ladder Logic programming. Similarly, for the PLC Digital Outputs Y0, Y1, Y2, the 24VDC positive connection was given to respective common terminals of the PLC (CO, C1), while the 24VDC negative connection was given to return of relay coil. The other end of the relay coil would be given positive VDC when the respective output connected to the relay (Y0, Y1, Y2) went to Logic HIGH, closing the relay driven load circuit.

v) Energy Meter: The energy meter was also fed with line AC power by means of a circuit breaker, and this was also input to a single one of the meter's voltage sensing terminals (to simulate the measurement of a single phase of the AC power).

vi) Loads: The loads, connected to AC line power by means of a separate circuit breaker, were divided into two categories:

a. *PLC driven loads*: These were the loads which simulated the industrial loads slaved to the PLC, which would be switched on and off, based on the Ladder Logic, to control the overall industrial power demand.

   The loads, consisting of a couple of light bulbs, were given power via relays controlled by the Industrial Load Management process. As soon as the output went to Logic HIGH, the relay would close and the load attached to it would turn on.

b. *Other industrial loads*: These loads were hooked to the AC line power without having to undergo the Industrial Load Management process check, in parallel. They simulated the other portions of the industrial load, which could not be switched off in any case e.g. certain lighting, process critical machinery etc.

   These loads consisted of 5 light bulbs, each of which could be switched on and off independently, to simulate the rise and fall of overall industrial load, which would be picked up by the smart energy meter and affect the switching of PLC driven loads, as per the Ladder Logic specified.

A final under- and over-frequency check was implement for both types of loads, in a separate Ladder Logic module, to ensure that none of the loads had to run in less than ideal conditions. This check was made to drive a third relay, whose switching action externally superseded that of the Industrial Load Management relays.

Basically, when an under- or over-frequency event was detected, by means of the energy meter, this relay would open (i.e. Digital Output would go to LOW), cutting off the AC power to all loads, so that none of the loads would be able to run. This included the PLC driven loads, even if the Industrial Load Management outputs were at Digital High.

The entire power supply of the SCADA system was provided through an extension board with power surge protection capabilities, in order to protect the expensive hardware from being affected by power surges which randomly occur in the country's power grid.

2.3.2 – PLC Ladder Logic

The PLC Station Number was set to 1.

- Fun150 Modbus:

  This built-in function supported by FBs 40MC PLC enables the sending of Modbus communication packets one after the other, to receive data from a remote device continuously. Once all messages have been sent, the cycle starts all over again, and until the stop bit is enabled. Here is its ladder logic implementation:

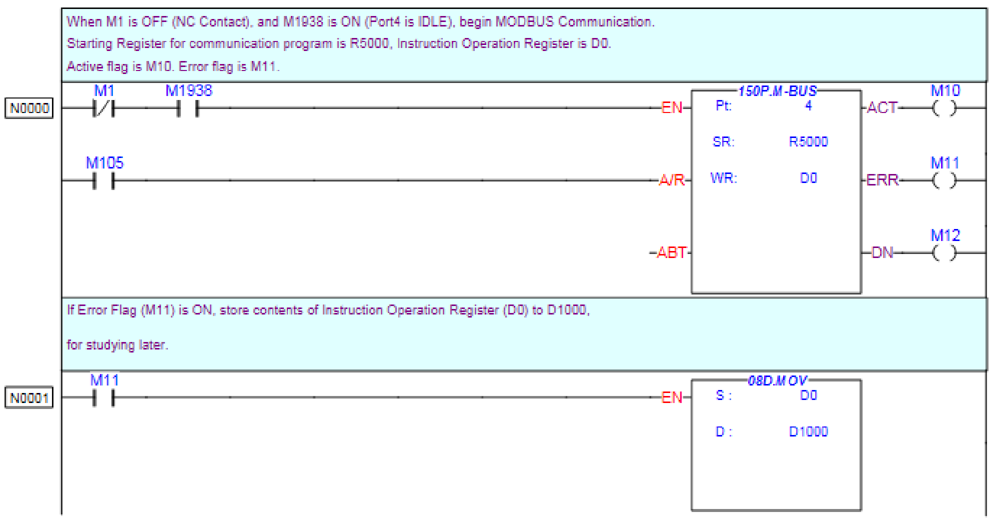
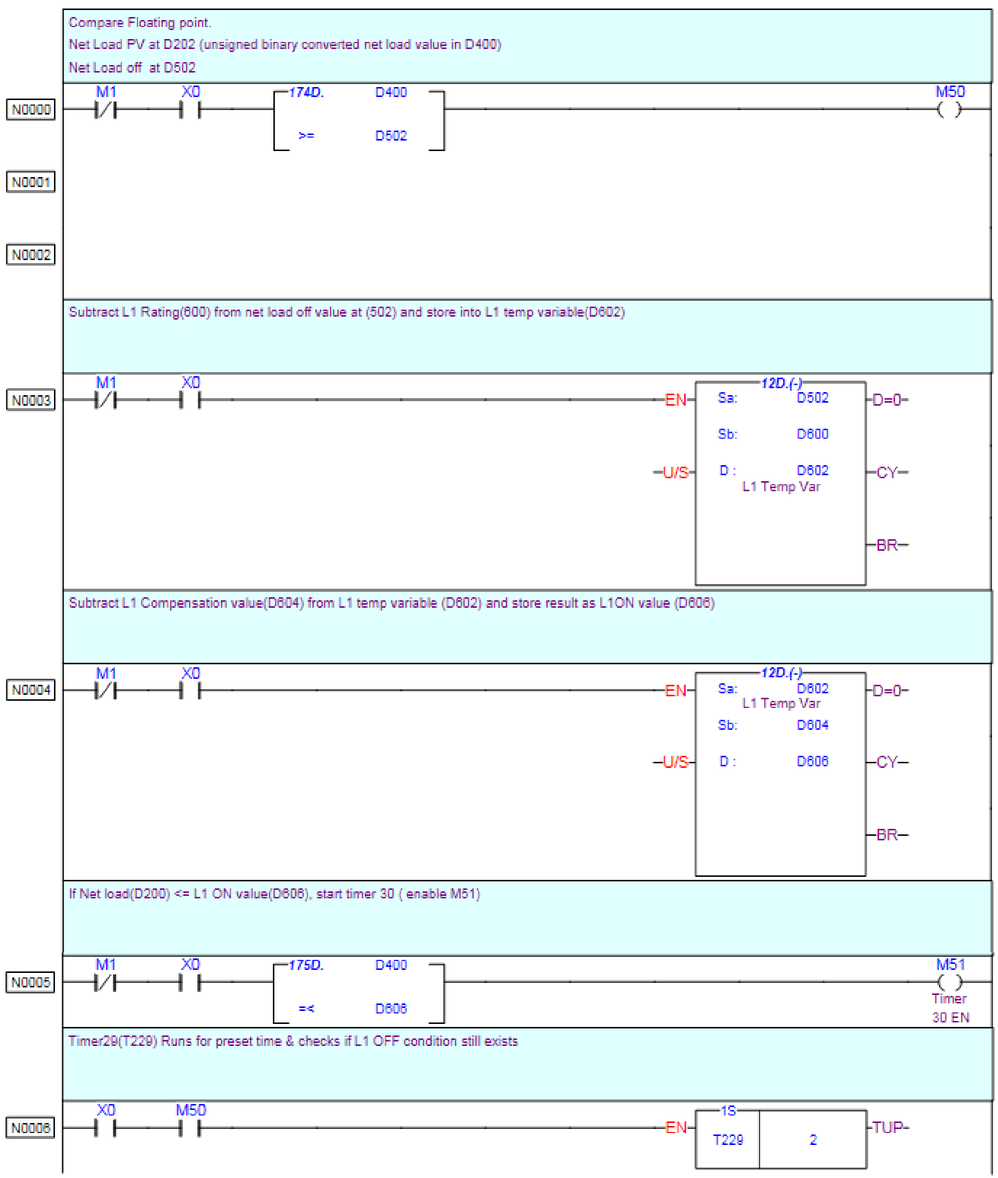
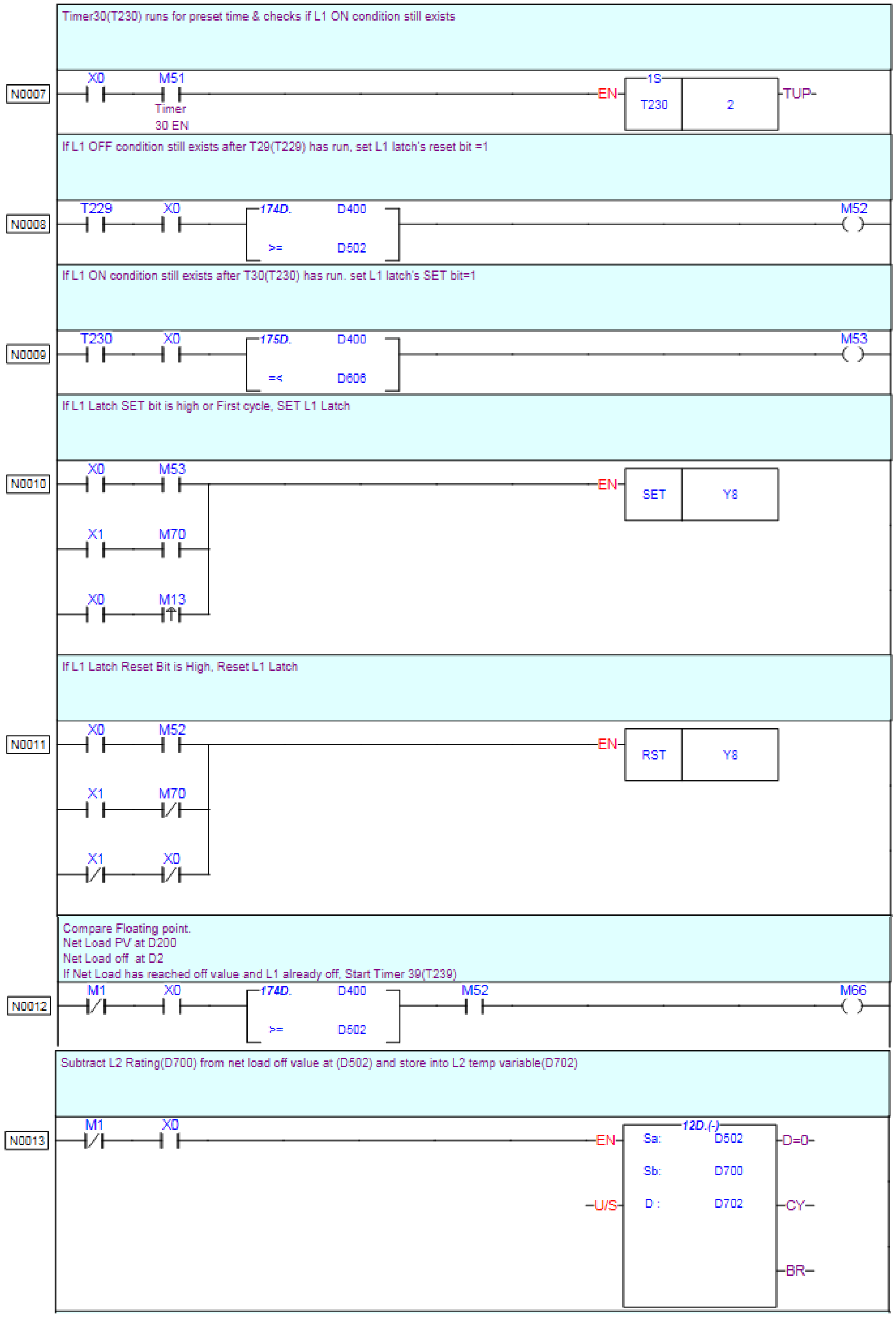


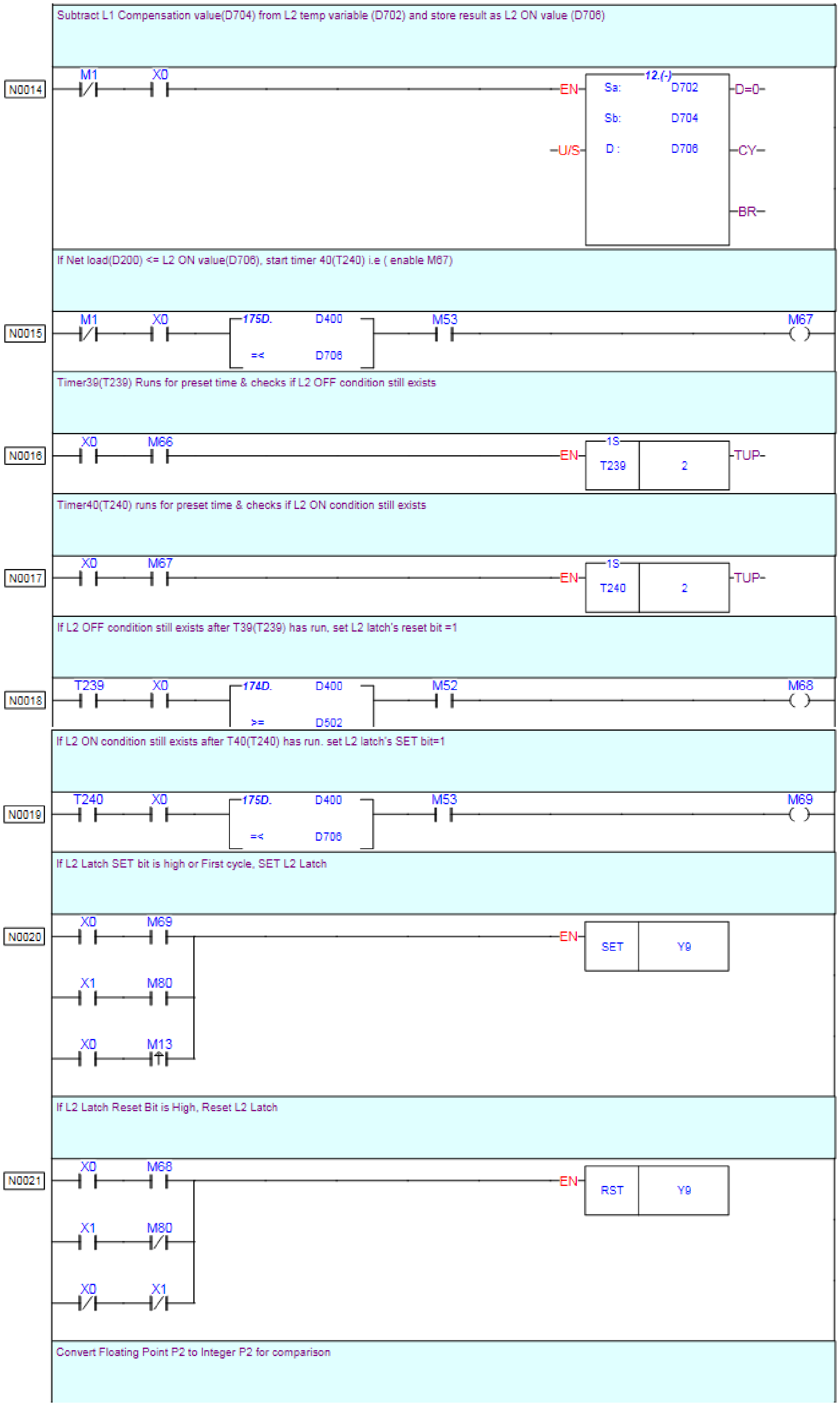
Figure 2 5 Ladder Logic for Fun150-Modbus function

- Load Management:

  Load Management is a core functionality of the SCADA system, and by constantly monitoring power consumption, it uses a priority scheme to balance the switching of non-essential industrial loads to ensure that the overall consumption does not exceed a specified threshold. This is the ladder logic of the process explained in its flowchart:




Timer30(T230) runs for preset time & checks if L1 ON condition still exists
N0007
X0
M51
Timer
30 EN
EN
1S
T230
2
TUP
If L1 OFF condition still exists after T29(T229) has run, set L1 latch's reset bit =1
N0008
T229
X0
174D.
D400
>=
D502
M52
If L1 ON condition still exists after T30(T230) has run. set L1 latch's SET bit=1
N0009
T230
X0
175D.
D400
=<
D606
M53
If L1 Latch SET bit is high or First cycle, SET L1 Latch
N0010
X0
M53
X1
M70
X0
M13
EN
SET
Y8
If L1 Latch Reset Bit is High, Reset L1 Latch
N0011
X0
M52
X1
M70
X1
X0
EN
RST
Y8
Compare Floating point.
Net Load PV at D200
Net Load off at D2
If Net Load has reached off value and L1 already off, Start Timer 39(T239)
N0012
M1
X0
174D.
D400
>=
D502
M52
M66
Subtract L2 Rating(D700) from net load off value at (D502) and store into L2 temp variable(D702)
N0013
M1
X0
EN
U/S
12D.(-)
Sa:
D502
Sb:
D700
D :
D702
D=0
CY
BR


Subtract L1 Compensation value(D704) from L2 temp variable (D702) and store result as L2 ON value (D706)
N0014
M1
X0
EN
U/S
12.(-)
Sa: D702
Sb: D704
D : D706
D=0
CY
BR
If Net load(D200) <= L2 ON value(D706), start timer 40(T240) i.e (enable M67)
N0015
M1
X0
175D.
D400
=<
D706
M53
M67
Timer39(T239) Runs for preset time & checks if L2 OFF condition still exists
N0016
X0
M66
EN
1S
T239
2
TUP
Timer40(T240) runs for preset time & checks if L2 ON condition still exists
N0017
X0
M67
EN
1S
T240
2
TUP
If L2 OFF condition still exists after T39(T239) has run, set L2 latch's reset bit =1
N0018
T239
X0
174D.
D400
>=
D502
M52
M68
If L2 ON condition still exists after T40(T240) has run. set L2 latch's SET bit=1
N0019
T240
X0
175D.
D400
=<
D706
M53
M69
If L2 Latch SET bit is high or First cycle, SET L2 Latch
N0020
X0
M69
X1
M80
X0
M13
EN
SET
Y9
If L2 Latch Reset Bit is High, Reset L2 Latch
N0021
X0
M68
X1
M80
X0
X1
EN
RST
Y9
Convert Floating Point P2 to Integer P2 for comparison

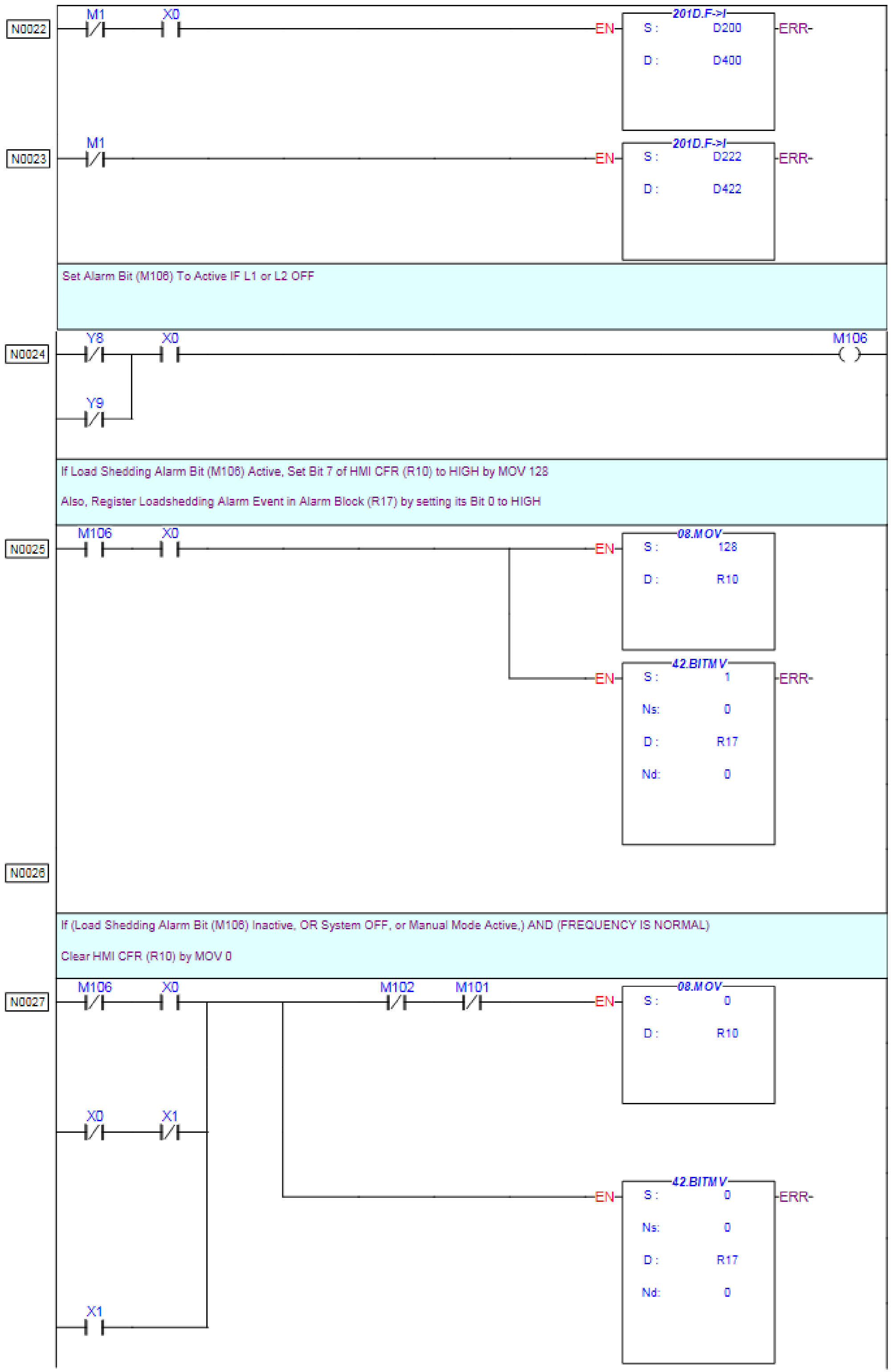


Figure 2 6 Ladder Logic for Load Management

- Frequency Protection:

  The over- and under-frequency check ensures that the loads overseen by the SCADA system do not run in less than ideal power system conditions, since this could adversely impact factory output, and even harm energized machines sensitive to frequency changes. Here is its ladder logic implementation:

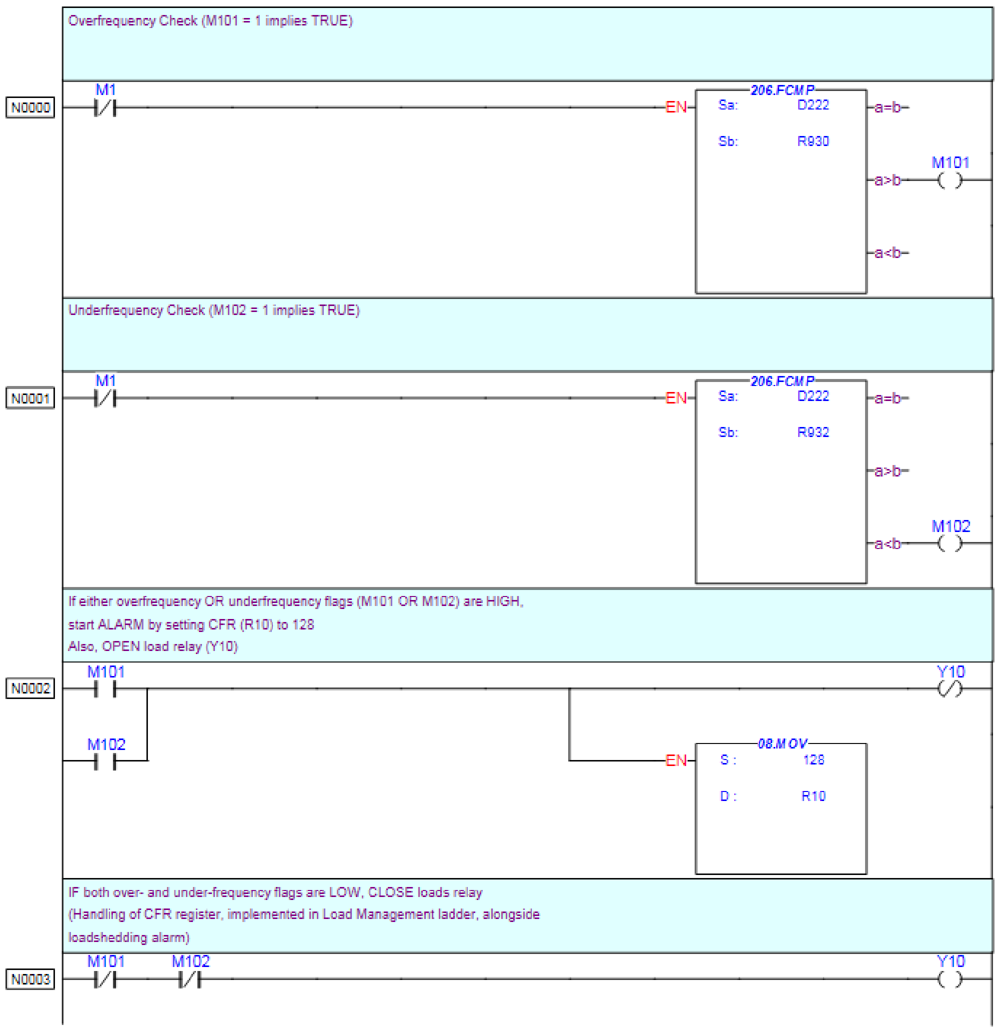


Figure 2 7 Ladder Logic for Frequency Protection

2.3.3 – HMI Configuration & Design

These are the general configuration details of the HMI design project. Note that Facon / Fatek FBs series has been specified, which automatically makes the designer follow the addressing conventions of this PLC device. R9 specifies the control block location on the PLC, which will be automatically read by the HMI over the serial RS-232 link (see section 2.3.4). By default, the next address i.e. R10, contains the Control Flag Register or CFR, which determines the turning on and off of the HMI's alarm, among other things.

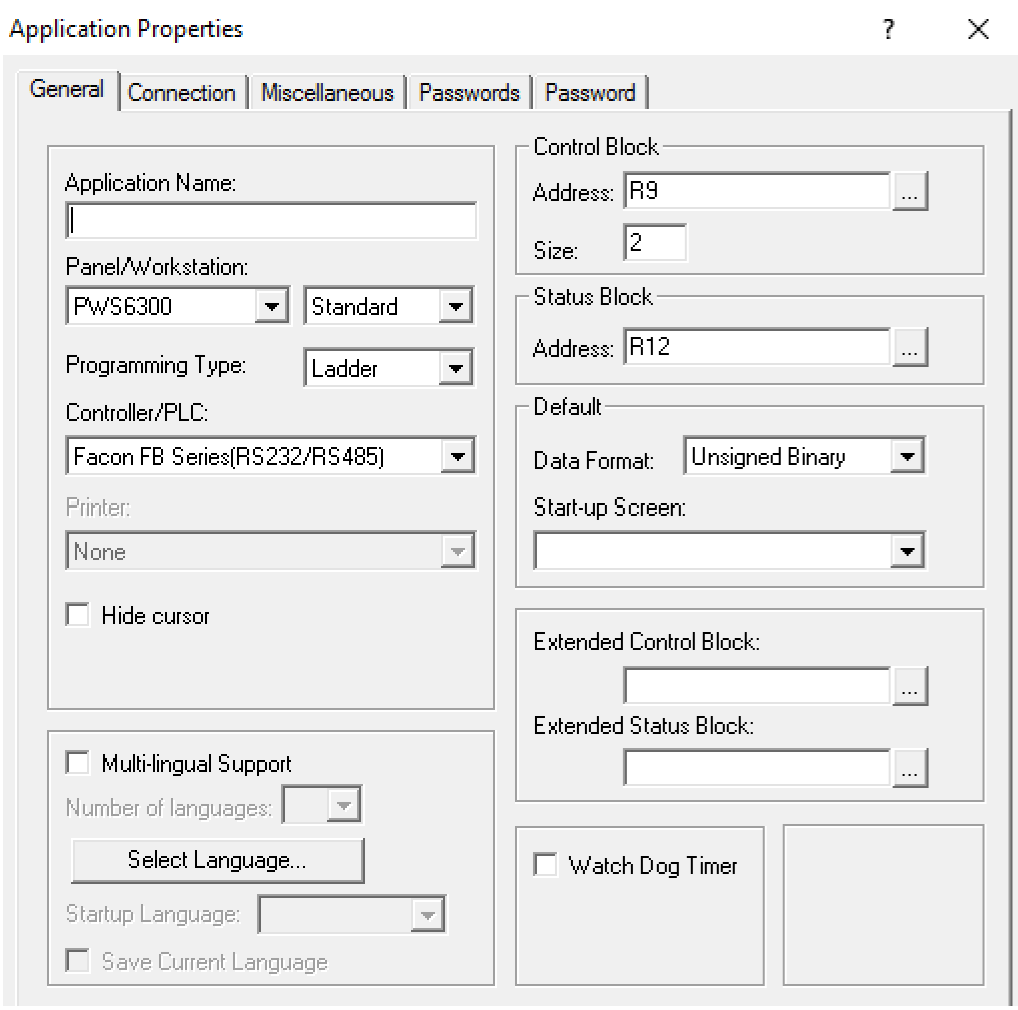


Figure 2 8 Configuration for HMI

The following screens were designed in this environment:

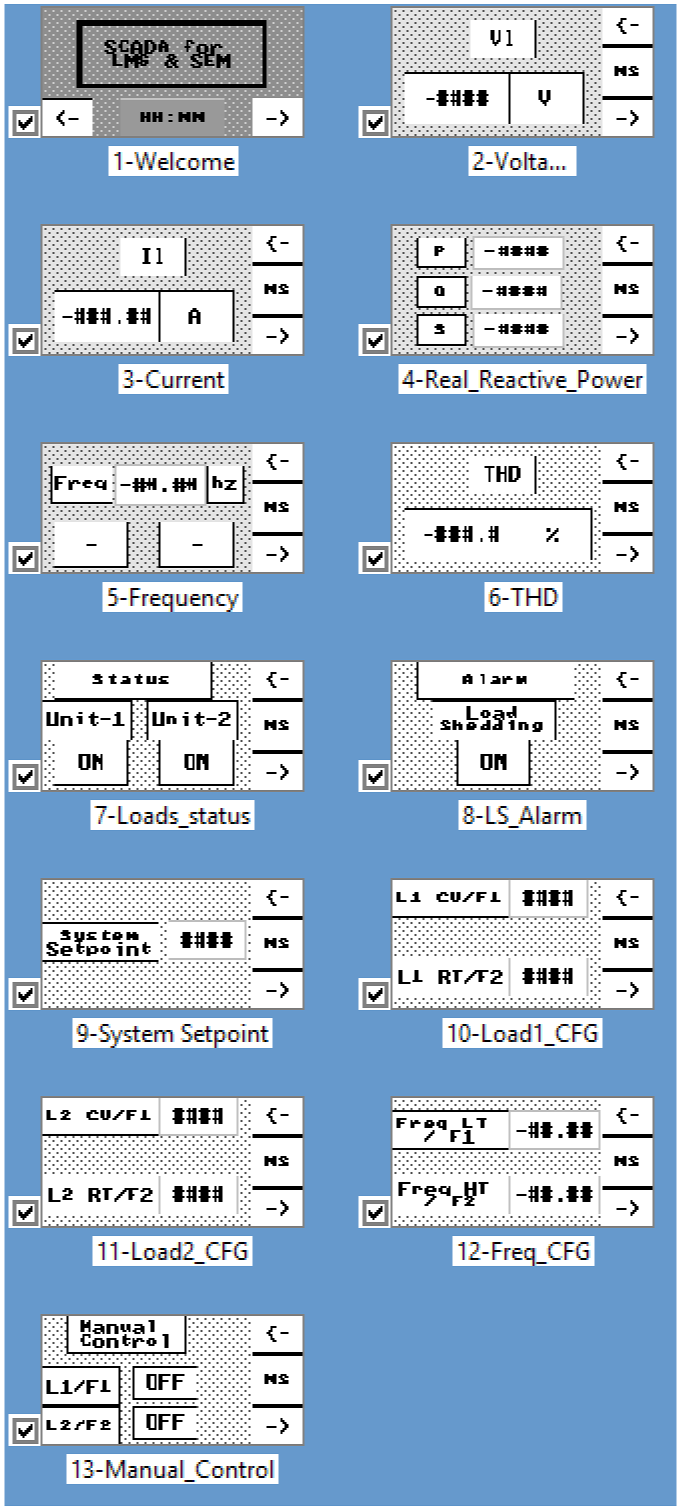


Figure 2 9 HMI screens

Here is a sample of how a Go To Screen (->) button was configured:

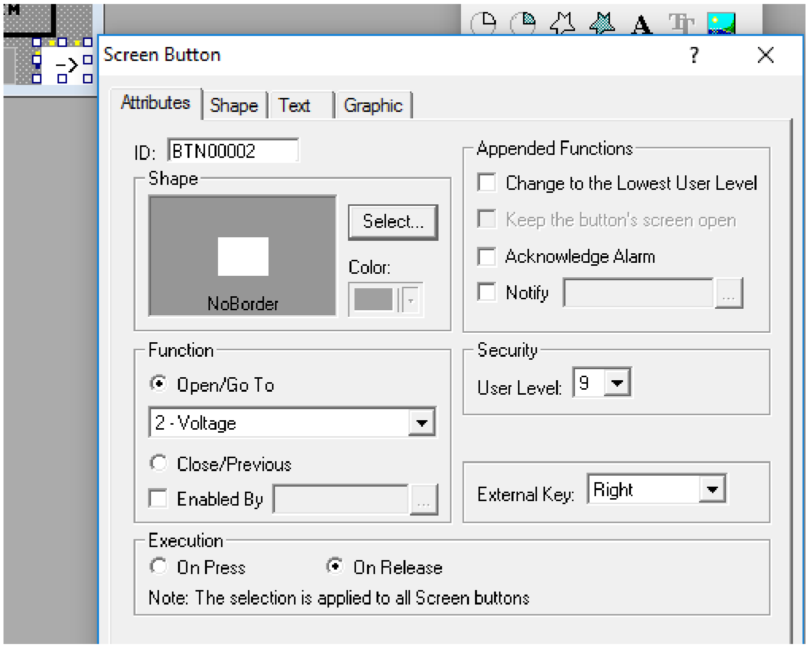


Figure 2 10 Setting up a push button

After double clicking on the button on the screen designer, the Function was specified as Open/Go To screen ‘2 – Voltage’. The button was mapped to the physical ‘Right’ external key.

Other input controls were set up in much the same way, in case of the On/Off buttons, a single bit of the PLC was specified as the variable. These On/Off buttons allow the operator to specify binary parameters to the SCADA system e.g. the manual on and off switching of loads slaved to the PLC.

Here is a sample of how a numeric output was configured:

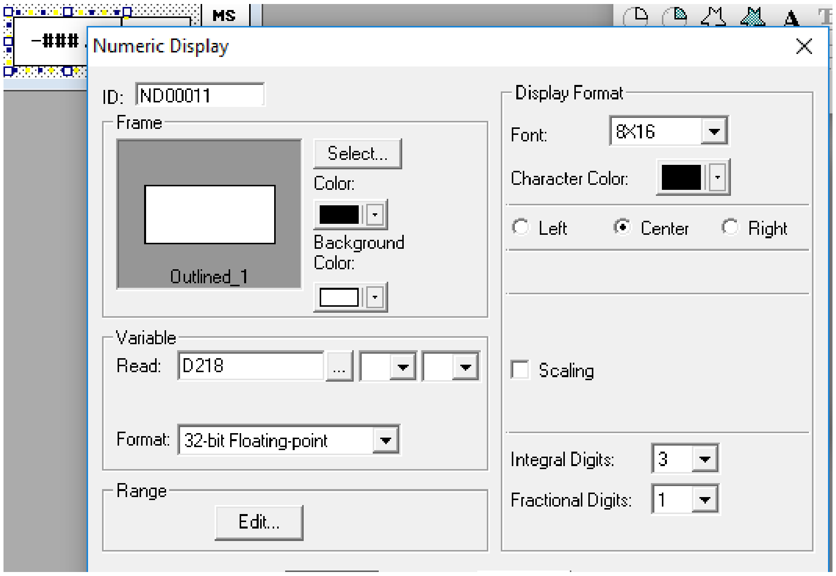


Figure 2 11 Setting up a numeric output

The numeric output object simply reads the value of a register (or registers) from the PLC and displays them on the HMI screen. The correct address and format must be specified, as well as the number of integers and decimals you want the operator to see.

Numeric input objects work in the opposite way – they can be made to accept numeric input from the operator and write it to a register (or registers) of the PLC. They must also be given an address from which they will read and display the information – normally it is specified as the same address as the input address, however different address can be specified.

2.3.4 – PLC to HMI communication

PLC to HMI communication was done over RS-232 serial.

The parameters were as follows on the HMI side:

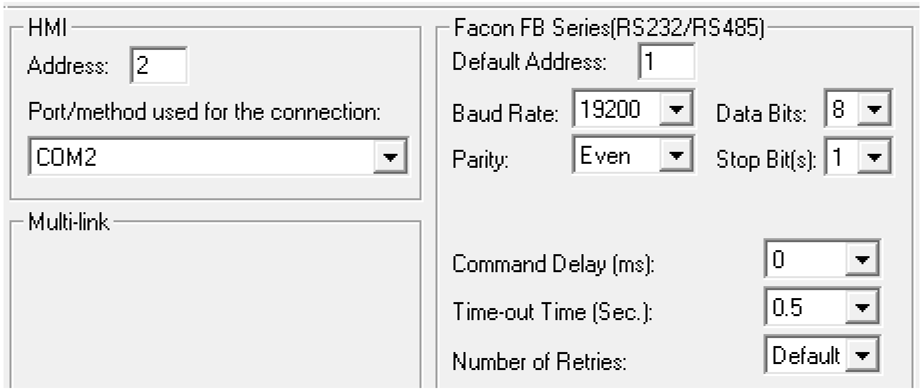


Figure 2 12 HMI Communication Parameters

Note that HMI Station Number was specified as 2 and PLC Station Number was specified as 1.

These settings were reciprocated in the Port3 (RS-232) communication parameters of the PLC.

2.3.5 – KMB SML 133 Smart Energy Meter Configuration

The energy meter was made to run with its factory settings, except for the current transformer ratio, which had to be specified in its configuration screen.

Nominal frequency was set to 50Hz by default, and communication parameters were also kept as default (see section 2.3.6). Since the project was restricted to single phase measurement for the time being, no further settings had to be adjusted.

Specifying the CT ratio:

After accessing the Parameter Screen #1 of the Energy meter, the CT primary nominal current was specified as 100A and CT secondary nominal current was specified as 5A, to match the rating of the CT being used to measure line current.

2.3.6 – PLC to Energy Meter Communication

The default communication parameters in the Energy Meter were:

Slave Address 1 – this is the ID of the Master in the SCADA system, which was the PLC in this case.

Bitrate 9600 bps – the speed at which communication between the two devices happens. Protocol 8 – this means that the size of each packet in the RS-485 serial communication would be 8 bits, with no parity bit.

These settings were reciprocated in the Port4 (RS-485) communication parameters of the PLC.

Chapter 3 – Testing and Results

3.1 – Hardware Simulation & Results

The functionality of the designed SCADA prototype was tested in real time, by simulating load variations, and mimicking operator input. The following testing conditions were created:

Industry Heavily Loaded:

With all essential loads the five (lamps fixed on the blue box) are running, the industrial load demand is much higher than the threshold value, hence the two non-essential loads (the two lamps below) slaved to the PLC must be kept off to minimize the power consumption. This is observed correctly:

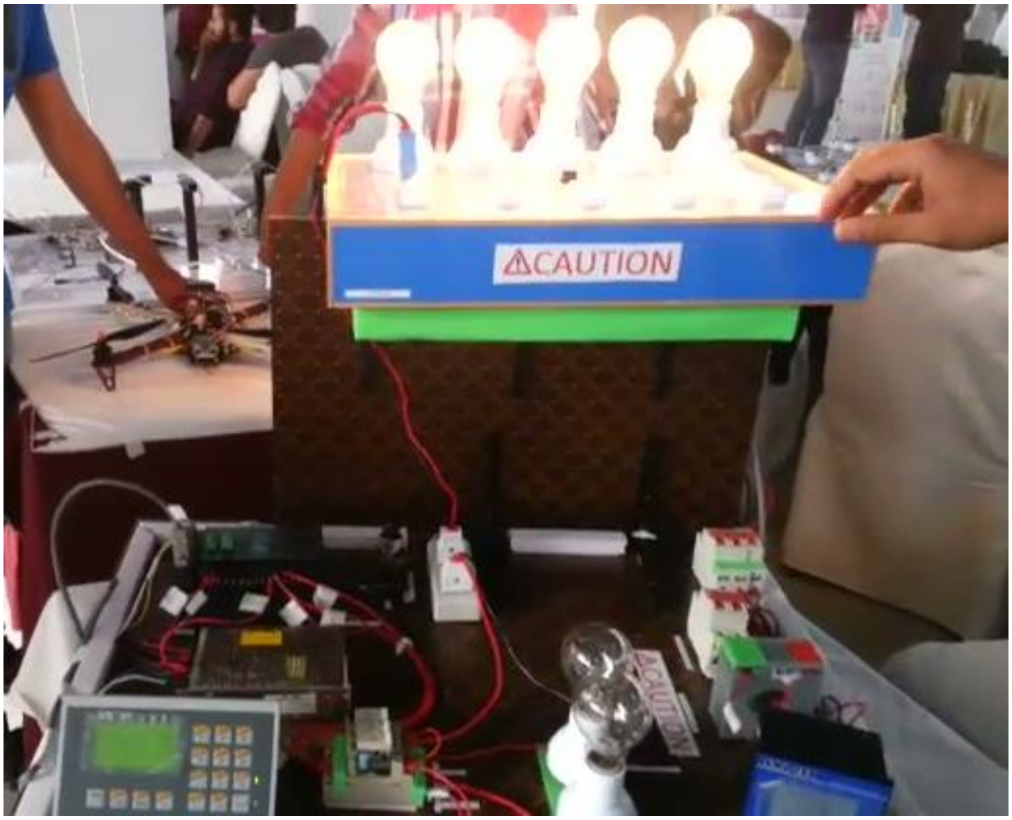


Figure 3 1 Fully Loaded Industry Simulation Results

Industry Moderately Loaded:

When the industry is moderately loaded i.e. some of the essential load is running (or in our case, 3 of the 5 lamps are on), the highest priority non-essential load (1 of the 2 lamps below) must be switched on by the PLC, since the threshold power consumption has not been reached yet. This is observed correctly:

Figure 3 2 Moderately Loaded Industry Results

Industry Lightly Loaded:

When the industry is lightly loaded, none of the essential loads are running (i.e. 5 of the 5 light bulbs are off), in this case, both of the non-essential loads (both of the 2 lamps below) must be switched on by the PLC, since the threshold is yet to be reached. This is observed correctly:

Figure 3 3 Lightly Loaded Industry Results

Manual Control Testing:

The SCADA’s HMI provides the operator with the facility to supersede the automatic Load Management mechanism. Once the multi-state switch is turned to specify the Manual Control Input as high to the PLC, the operator can use the HMI screen to directly control the switching of each of the PLC-slaved loads (the 2 lamps below).

For instance, as the operator specifies Load 1 to turn on:

Figure 3 4 Turning Load 1 on manually by pressing F1 key

Load1 i.e. the highest priority lamp among the 2 lamps below turns on:

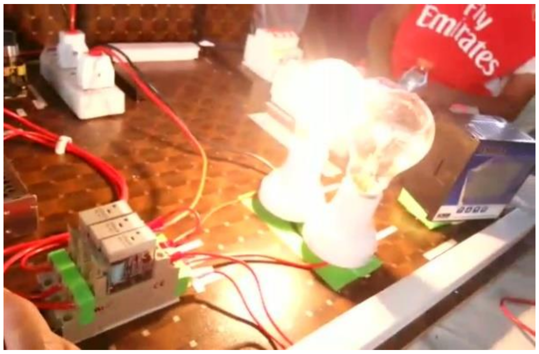


Figure 3 5 Lamp 1 turns on as the operator sets Load 1 to on in the HMI

As Load2 is turned on by pressing the F2 key:

Figure 3 6 Turning Load 1 on manually by pressing F2 key

Load2 i.e. the next priority lamp among the 2 lamps below turns on:

Figure 3 7 Lamp 2 turns on as the operator sets Load 2 to on in the HMI

Testing results:

The following table summarizes the results of our testing strategy:

Test	System Mode	Expected Result	Actual Result
Fully Loaded Industry	Auto	Both slaved loads off; alarm on	Both slaved loads off; alarm on
Moderately Loaded Industry	Auto	Higher priority slaved load on; alarm on	Higher priority slaved load on; alarm on
Lightly Loaded Industry	Auto	Both slaved loads on; alarm off	Both slaved loads on; alarm off
Turn Load1 On Manually	Manual	Higher priority slaved load turns on; alarm off	Higher priority slaved load turns on; alarm off
Turn Load2 On Manually	Manual	Lower priority slaved load turns on; alarm off	Lower priority slaved load turns on; alarm off

Table 3 1 Result Summary

Note that frequency protection testing conditions could not be deliberately simulated, however, during spontaneous under- and over-frequency events, the system behaved correctly i.e. whenever the system frequency was not in desirable range, the entire set of loads (both sets of lamps) was cut off from line power and an alarm would sound.

This continued until desirable frequency range was once again met.

Chapter 4 – Conclusion

Having conducted our testing scheme, and obtained positive results in all scenarios, we have reached the conclusion that the SCADA Design for Load Management & Smart Energy Management is ready to move on to its practical implementation phase.

While the Smart Energy Management feature is yet to be fully implemented, we remain optimistic that our sponsors, once they see the results and benefits of the Load Management feature, will be more than willing to source its hardware.

Chapter 5 – Future Expansion Prospects

Midway through the implementation of the Smart Energy Management part of the project, we realized that it would not be cost efficient to create a solution that could only control the automatic switching of just a few building lights, unless intermediate control was implemented on a separate micro-controller.

Our reservations were compounded by the fact that micro-controllers have been found to unreliable in rugged industrial environments.

Therefore, we have proposed a more advanced Smart Energy Management solution incorporating a Digitally Addressable Lighting Interface to our sponsors. This system uses a master / slave control scheme to dynamically adjust the light intensity (and hence the power consumption) of hundreds of lights, by employing a bus topology, in which each slave is given a unique ID and a command signal containing a slave ID is relayed to the bus. Only the slave with the matching ID will alter its light intensity.

In this way, a single PLC can be used to control hundreds of building lights through a simple RS-232 / DALI bridge, as opposed a single PLC being only able to control a few building lights directly in the case of the previously proposed Smart Energy Management system.

REFERENCES

[1]Beijer Electronics. (n.d.). *Beijer Electronics - PWS 6300S*. Retrieved from beijerelectronics.com.tw: http://www.beijerelectronics.com.tw/web/web_en_be_tw.nsf/alldocuments/E27BDA38A9B8B4F4C125721B00360488

[2]Communication Technologies, Inc. (2004). Supervisory Control and Data.

[3]FATEK AUTOMATION CORP. (n.d.). *FBs-40MC*. Retrieved from fatek.com: http://www.fatek.com/en/prod.php?act=view&no=12

[4]FATEK AUTOMATION CORP. (n.d.). *FBs-B2A1D*. Retrieved from fatek.com: http://www.fatek.com/en/prod.php?act=view&no=74

[5]FATEK AUTOMATION CORP. (n.d.). *FBs-CM25E*. Retrieved from fatek.com: http://www.fatek.com/en/prod.php?act=view&no=52

[6]Keith Stouffer, J. F. (2006). Guide to Supervisory Control and Data Acquisition (SCADA) and Industrial Control Systems Security.

[7]KMB systems s.r.o. (n.d.). *SML 133 - KMB systems*. Retrieved from kmb.cz: http://www.kmb.cz/index.php/en/digital-meters/digital-panel-multimeter-sml-133

[8]Modbus Organization, Inc. (n.d.). *Modbus FAQ*. Retrieved from modbus.org: http://www.modbus.org/faq.php

[9]Schneider Electric Telemetry and Remote SCADA solutions. (2012). SCADA systems.

[10] P. Shunmugakani, A. A. Selvan, R. V. Ananth and K. A. Jerome, "Building Management System using PLC and SCADA," *JCHPS Special*, no. 9, 2015.

[11] M.-Y. Cho and J.-C. Chen, "A SCADA System Application in Load Management," in *Proceedings of the Fifth International Conference on Electronics Business*, Hong Kong, 2015.

[12] S. Kumar, J. P. Rajwar and A. K. Thakur, "Building Management System using PLC and SCADA," *International Journal of Science & Engineering Research*, vol. 4, no. 5, 2013.

[13] P. Vivekanandan, D. Parakash and J. Anitha, "Building Management System Using PLC," *Indian Journal of Emerging Electronics in Computer Communications*, vol. 2, no. 1, 2015.

[14]K. Kaur and P. R. Kaur, "Energy Management System using PLC and SCADA," *International Journal of Science & Engineering Research*, vol. 3, no. 11, 2014.

ABBREVIATIONS

DTR: Data Terminal Ready

DCS: Distributed Control System

HMI: Human Machine Interface

IED: Intelligent Electronic Device

IP: Internet Protocol

LAN: Local Area Network

MTU: Master Terminal Unit

PLC: Programmable Logic Controller

RTU: Relay Terminal Unit

Rx: Receiver

RTS: Request to Send

SCADA: Supervisory Control and Data Acquisition

Tx: Transmitter

WAN: Wide Area Network