DEVELOPMENT OF A POLE-MOUNTED CIRCUIT BREAKER TELECONTROL UNIT.

by

FREDERIK ANTONIE GROBLER

DISSERTATION

submitted in fulfilment of the requirements for the

MAGISTER TECHNOLOGIAE: ENGINEERING: ELECTRICAL

in the

FACULTY OF ENGINEERING

at the

TECHNIKON FREE STATE

***Supervisor:* MR. LW vd MERWE**

and

***Co-supervisor:* MR. G.D. JORDAAN**

JUNE 1996

Central University of Technology, Free State

ACKNOWLEDGEMENTS

All glory to God Almighty, for persistence and guidance given throughout this research.

Appreciation to Mr. GD Jordaan, for his time, patience and motivation when matters seemed very dark.

Special thanks to Mr. LW vd Merwe, for his willingness to act as supervisor, and to Mr. HF Coetzer for his assistance with grammar in the text.

To Frank Edwards, and the Telecontrol technicians, my appreciation for their assistance, and the use of the Telecontrol laboratory.

Thanks to Eskom, for the time and financing of this research project.

Appreciation to my wife Melinda, and my daughters, for their patience during this time.

SUMMARY

When Alexander Graham Bell invented the telephone in 1876, he never envisioned the wealth of late 20th century high technology applications of his intended simple personal communications device.

With this investigation, advantage was taken of combining the existing Eskom communications network with new-technology SCADA equipment, in order to allow communications from the control centre at Bloemfontein to the actual pole-mounted breaker in the field, covering the Free State distributor.

Due to the high costs, and the complex maintenance performance of the existing network, a telecontrol system was developed that requires minimal maintenance and provides high reliability in order to promote efficient functioning of the network.

With this development the use of existing products, skills and technology were applied to obtain effective pole-mounted telecontrol, to enhance the use of present technology in the rural areas of the distributor.

Central University of Technology, Free State

UITTREKSEL

Met die ontdekking van die telefoon deur Alexander Graham Bell in 1876, het hy sekerlik nooit gedink dat dit sou lei tot die huidige tegnologiese ontploffing van die 20 ste eeu, waarin kommunikasie een van die belangrikste hulpmiddels geword het nie.

Met hierdie ondersoek is die geleentheid benut om die bestaande Eskom kommunikasie-netwerk te kombineer met beskikbare tegnologie en telebeheer toerusting (SCADA), ten einde kommunikasie tussen die beheersentrum in Bloemfontein en paalgemonteerde stroombrekers in die Vrystaat distribueerder te bewerkstellig.

A.g.v die hoë kostes om die bestaande netwerk te onderhou, is daar 'n telebeheer stelsel ontwikkel wat weinig of baie min onderhoud verg, en werklik daartoe kan bydra dat die elektriese kragnetwerk seepglad funksioneer.

Daar is met hierdie ontwikkeling gepoog om bestaande produkte, vakmanskap en tegnologie in te span om effektiewe telebeheer toe te pas op die streek se landelike lyne en paalgemonteerde brekers.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

CHAPTER 2

THEORETICAL BACKGROUND

CHAPTER 3

METHODS AND TECHNIQUES

CHAPTER 4

COMMUNICATION SYSTEM HARDWARE.

CHAPTER 5

MASTER STATION HARDWARE AND SOFTWARE CONFIGURATIONS

CHAPTER 6

REMOTE ACCESSORIES AND MODIFICATIONS

CHAPTER 7

EVALUATION

CHAPTER 8

SUMMARY

ANNEXURES

FIGURES

CHAPTER 1

CHAPTER 2.

CHAPTER 3.

CHAPTER 4.

CHAPTER 5.

CHAPTER 6.

CHAPTER 7.

APPENDIX A.

APPENDIX C.

Central University of
Technology, Free State

ALPHABETICAL LIST OF SYMBOLS USED

A = Ampère

ac = Alternating current

ACIA = Asynchronous Communication Interface Adaptor

A/D = Analogue to Digital

ANA_X = Analogue number x

CIU = Central Interface Unit

CM = Channel Monitor

CMOS = Complimentary Metal Oxide Semiconductor

CPU = Central Processor Unit

CT = Current Transformer

dB = Decibels

dc = Direct Current

DDE = Dynamic Data Exchange

DI = Direct Interrogate

DIN_X = Digital Input Number x

DIRQ = Decoder Interrupt Request

DLL = Dynamic Link Library

EEPROM = Electrically Eraseable Programmable Read Only Memory

EOB = End Of Bit

ERTU = Enhanced Remote Telecontrol Unit

FS = Frame Synch

FSK = Frequency Shift Keying

HDOT_X = Handdress operated tag number x

Hz = Hertz (frequency)

IC = Integrated Circuit

LAN = Local Area Network

LCU = Line Control Unit

LED = Light Emitting Diode

mA = milli-amp

M & E = Signalling pulse

MMI = Man - Machine - Interface

MPU = Microprocessor Unit

MPS = Microprocessor Subsystem

MRTU = Modular Remote Telecontrol Unit

OW = Operator Workstation

PDO = Pulse Duration Output

PIA = Peripheral Interface Adaptor

PLL = Phase Locked Loop

PMRTU = Pole Mounted Remote Telecontrol Unit

PTT = Push To Talk

PV = Photovoltaic

RAM = Random Access Memory

REJ = Reject

Rf = Radio Frequency

ROM = Read Only Memory

RTU = Remote Telecontrol Unit

Rx = Receive

SCADA = Supervisory Control And Data Acquisition

SCI = Serial Communications Interface

SPI = Serial Peripheral Interface

Tx = Transmit

V = Volts

VT = Voltage Transformer

CHAPTER 1

INTRODUCTION

1.1 Telecontrol background.

Over the past decades, an art of measurement and control from remote distances has been developed in industry. Demand for this work has originated, and continues in the electricity supply, water distribution and manufacturing fields. For the purpose of this research project the focus was on remote control in the electrical field.

According to Strock [20, p. 1] telemetry virtually means measuring at a distance, or remote measuring. The term could be applied to measurement of the condition or location of an object at a distance. Telemetering has grown to mean more specifically the observation of variables and physical measurements at a remote location.

The first known implementation of telemetering was that used by Shilling. It was used during 1812, for the firing of mines in Russia. According to Gruenberg [3, p. 1-4], the art has developed toward industrial applications, making use of wired techniques and radios.

Remote control or Telecontrol is an extension of the concept of remote measurement. In remote control, actuators are included to make a change at the remote location.

A remote control system can be defined as a closed-loop system that must consist of at least the following elements [3, p. 15-2]:

- ⇨ Sensors of information.
- ⇨ A transmission system to communicate information to a remote control point.
- ⇨ A control point that includes a human or automatic decision-making system.
- ⇨ Devices to translate information into appropriate control signals.
- ⇨ Links to communicate information to actuators at remote action points.
- ⇨ Actuators operated by control signals to effect responsive-controlled operations.

The original concept of a telecontrol system was to reproduce measured quantities as accurately as possible at a distance from the source of these data. Subsequently, the concept was broadened to include activation of devices from a remote location.

1.2 The electricity supply network.

The challenge of supplying electricity to smaller users, such as farmers, towns and smaller mines has to be met by Eskom. Because of this contribution, Eskom is recognised as an undisputed leader in the field of electricity supply in the RSA. The consumers are reached by means of power lines, feeding from electrical substations.

At present, the power distribution system can be divided into four categories, namely:

1) Main transmission substations. These stations are part of the backbone of the electricity distribution network in the RSA.

2) Distribution substations. These are substations primarily feeding larger customers, such as cities, mines, industries and factories.

3) Reticulation substations. These stations are used to supply smaller towns, mines and traction networks.

4) Pole-mounted breakers and rural distribution lines. This category is mainly used on rural power networks. The function of pole-mounted breakers is to isolate faulty lines feeding small power users.

The Free State Region has more than 25 000 km of overhead reticulation line, divided into manageable segments. As the power lines are exposed to nature, it is humanly impossible to guarantee an uninterrupted supply of electricity.

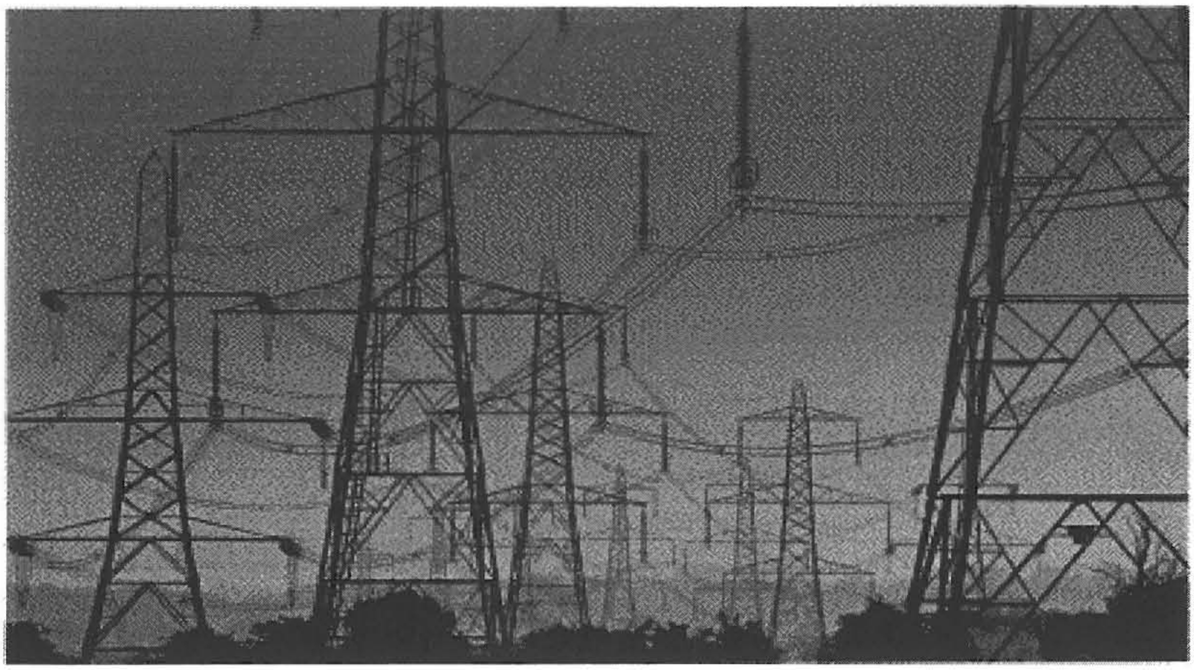


Fig. 1.1: A typical example of distribution powerlines.

When a permanent line fault occurs, the faulty section is isolated by the manual or automatic operation of protection devices, and the supply to the non-faulty line sections can be restored. At present, Eskom is often unaware of such an interruption, until the customers respond by complaining about loss of power.

1.3 Electrical circuit breakers.

Laughton and Say [5, pp. 15-37] mentioned that about 80% of the earth faults on overhead lines are of a transitory nature. These result from lightning, birds or other causes, and no damage to the equipment is sustained. However, the ionized path caused by the transient flash-over permits a follow current to flow, which must be cleared by a circuit breaker operation. This causes an outage. Such outages can, however, be limited to a few seconds in certain cases by the use of auto-reclose circuit breakers.

In order to maintain the Free State Region's overhead reticulation power lines, the lines are divided into segments by pole-mounted breakers (or reclosers) and sectionalisers.

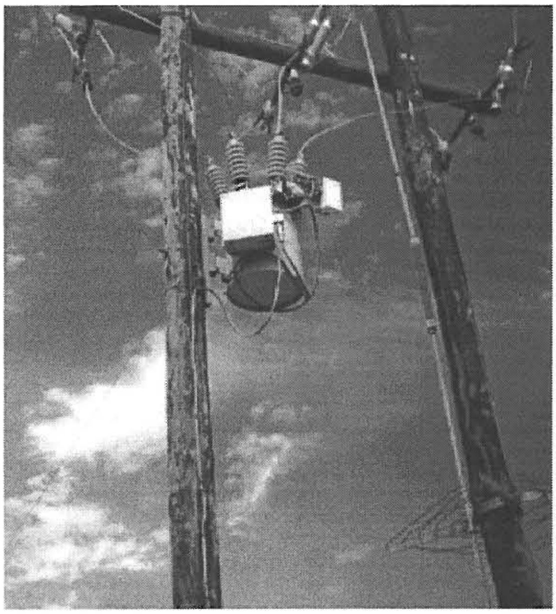


Fig. 1.2: Pole-mounted breaker mounted on a pole structure.

A recloser or pole-mounted breaker is a self-controlled device which senses distribution system overcurrents, and interrupts the circuit to clear faults. It automatically recloses to restore service if a fault is temporary. Several attempts may be made in clearing and re-energising the circuit, and if the fault still exists, the recloser locks-out. The opening sequence can be all fast, all delayed, or a number of fast, followed by delayed up to a total of four reclose attempts. Fast operations clear temporary faults, such as birds or small objects on the transmission lines, before branch line fuses are damaged. Delayed operations allow time for down-line protective devices to clear the fault so that permanent faults can be confined to a smaller section of the system.

McGraw Edison Instruction Manuals describe a sectionaliser as an automatic circuit opening device [10, p. 1]. After a circuit has been de-energised by a backup protective device (such as a recloser), the sectionaliser isolates the faulted portion of the distribution line. After the fault has been isolated, the rest of the circuit is returned to service upon reclosure of the backup device. The sectionaliser operates by counting the overcurrent interruptions of the backup device. Sectionalisers can be set to open after one, two or three counts, within a predetermined time span. A sectionaliser opens during the open interval of the backup. Although it cannot interrupt faults, it is rated to be closed onto a fault. A sectionaliser can be used in place of a fuse or between a reclosing device and a fuse.

Reclosers and sectionalisers are mostly hand-operated, and require the use of manual closing tools and accessories when de-energised. This complicates remote control implementation. During the course of this research project the electronically remote tripping and closing of these devices via a remote control unit from a central point was nevertheless successfully implemented.

1.4 Sectionalising.

One of the most successful methods used by Eskom to locate a faulty line section is sectionalising. This is done by dividing the line into sections by means of isolators such as pole-mounted breakers and sectionalisers. This has the effect that in the event of a fault, power would only be removed from the faulty part of the line.

The time taken to sectionalise the line and isolate the fault determines the customer outage time. This may take several hours, because most of the breakers are situated on rough terrain. If the line could be sectionalised by remote operation of the switchgear, much time would be saved.

Most of the rural power lines function at voltages of between 6 000 volt and 33 000 volt, and human errors occurring during operations on these lines can cause loss of human life. This risk would be eliminated to a considerable extent by implementing telecontrol on the pole-mounted breakers. Development in the field of pole-mounted remote telecontrol units has, however, lagged behind other remote control implementations.

1.5 Aim of the project.

The aim of this research was to provide a SCADA (Supervisory Control and Data Acquisition) facility for pole-mounted breakers. Such a facility provides up-to-the-minute information on network status and load flow. This would enable the control centre to control the network, rather than purely react to customer complaints, or field-driven requirements for operating purposes. It would also contribute, to a great extent, to improved customer satisfaction, because of a more reliable and stable electricity supply.

It was important for both the reticulation system and the pole-mounted system to be part of the same source of information on which the processor operates. This would enhance the SCADA effectiveness, and would insure that the alarm processor sees a complete view of the distribution and reticulation system.

1.6 Communication considerations.

Eskom has developed an integrated multichannel radio network reaching all major power and distribution stations, the regional control centre and all depots.

The backbone of this private communications network consists of UHF radio spurs to the smaller stations, and microwave to the Regional Control Centre. For mobile-radio communications, used mostly on the distribution or reticulation networks, a VHF repeater network, integrated into the multichannel communication system, has been established. This is ideal for the concept of shared voice and data systems.

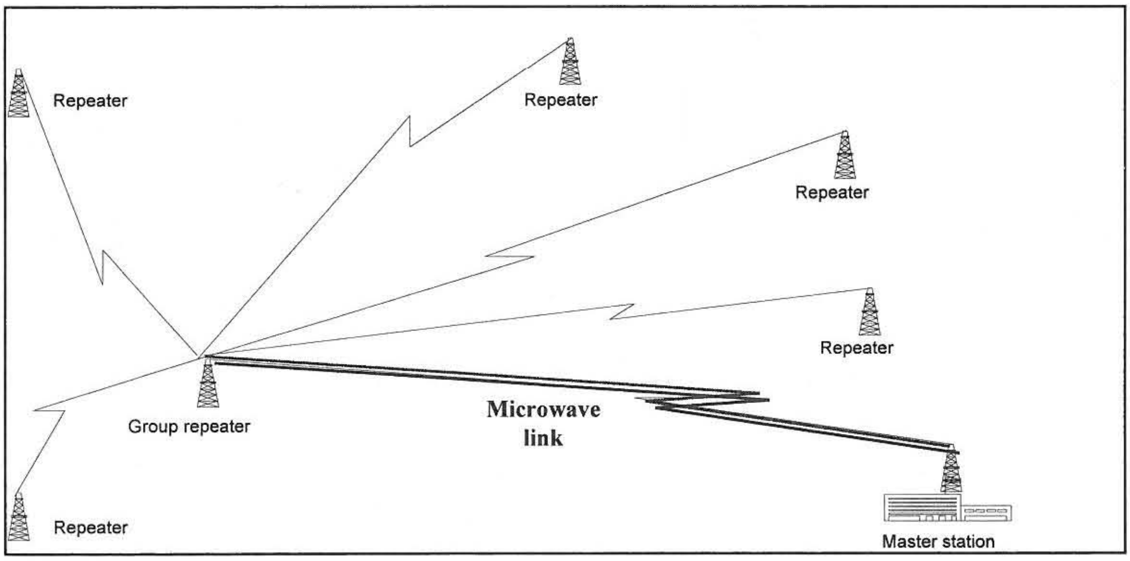


Fig. 1.3: Free State Region repeater multiplexing.

Figure 1.3 shows how the radio system serves approximately 500 users via repeaters, grouped on a district basis into groups radiating from the regional control centre. The grouping of repeaters gave rise to interference problems, and hence splitting of repeaters was implemented. As a result, each repeater is received individually at the control centre. This has increased the traffic carrying capacity of the system enormously, and also reduced the interference, especially that caused by telecontrol. Each repeater is connected to the control centre by an independent channel. Also, the control links on the mobile-radio system are operated on a full duplex basis, which reduces radio interference, and speeds up the pick-up time of the system.

The telecontrol system has benefitted from this in that a shorter pre-transmission mark is required to allow for channel pickup. Previously all radios had operated on an open channel. A call was set up by calling the other party by name. This was extremely cumbersome, and wasteful of both callers' time and air time. Nowadays a call is set up simply by dialling a code that sets off an alarm at the called party's receiver, returning an answer back indication, as soon as the call is taken.

More telecontrol traffic can be carried over a network with selective calling, because the irritation factor of the telecontrol is removed, and the radio remains quiet until it only opens upon receipt of its own code. This allows for more telecontrol outstations to be installed, and has thereby facilitated the implementation of pole-mounted telecontrol.

1.7 Problems identified.

As the master station would be replaced by another unit in future, this necessitated the development of an MRTU unit that could be adapted to other future master units, as long as the same protocol was used. Database configurations therefore had to be made flexible and adaptable.

Some problems concerning the adaptability of auto-reclosers to be controlled and monitored, were found. This has necessitated modifications to many of the auto-reclosers and these are discussed fully in this document.

Existing supervisory control and data acquisition (SCADA) remote units in substations are currently being replaced by enhanced remote terminal units (ERTUs). A large number of modular remote terminal units (MRTUs) will be decommissioned.

Instead of purchasing new units, the decommissioned units may be converted for use as pole-mounted breaker MRTUs, and in this way can lead to saving an enormous amount of money.

1.8 Conclusion.

Considering the fact that the concept of telecontrol has existed since 1812, the issue of controlling and monitoring pole-mounted circuit breakers seems to remain in abeyance.

Providing Supervisory Control and Data Aquisition (SCADA) for pole-mounted breakers will definitely improve the quality of electrical supply to the customers. Not only will this contribute to better customer relationships, but it will improve the global power-network operation, as more detailed information on minor networks becomes available. Replacing hand-operated actions with computer-driven actuators eliminates unnecessary human risks, and saves much time and travelling.

Supervisory systems offer a higher reliability and availability of the entire power system due to self-diagnosis, and as a consequence lower maintenance costs. The system has only to be maintained in case of an indicated disturbance, and need not be checked periodically.

Enormous savings in funds may be realised by utilizing the existing mobile-radio communication network as a communication medium for the pole-mounted breakers.

1.9 Personal involvement.

The author's involvement with SCADA, telecomms and radio equipment began in 1984. A lack of telecontrol facilities in the pole-mounted breaker and rural environment of ESKOM was detected whilst working in the System Operations department.

While working with the control staff and outage schedulers, the author detected a great lack of information in the field of pole-mounted breakers. An urgent need also existed for controlling these pole-mounted breakers in the control centre environment. Since there was no unit available at that stage suitable to control and monitor the state and condition of reclosers, the author assembled a unit by using different off the shelf modules available at that stage.

In order to solve this problem, the author studied various types of electrical stations and the requirements thereoff to be suitable for SCADA. The first step was for information to be gathered for all types of equipment that existed in the region. This involved a lot of travel to all Eskom regions. Discussions with the distribution officials, controlling staff and telecommunications technicians followed.

The author decided to make use of the existing radio network for economical reasons. Various types of Distribution, Regional and Reticulation substation telecontrol units were explored, but in vain. The author decided to assemble a unique unit, by using different modules and electronic equipment. Chapter 1 contained a brief explanation of telecontrol, where it is used, and what type of communication was suitable for the implementation of this project.

The availability of good radio coverage throughout the Free State Region, which was already established and in daily use for voice communication, facilitates the use of this pole-mounted telecontrol system.

Telecontrol enables the user to remain in a convenient location (control centre) and monitor events in an inconvenient location, or an inaccessible venue (pole-mounted breaker site). Applications therefore, are limited only by the number of such venues to be monitored, and by the cost-effectiveness of such data transfer.

The master station consists of a radio, encoder and decoder modules, central interface unit (CIU), line control unit (LCU), a main file server, a backup file server and the operator workstations (OW).

The modular remote terminal unit (MRTU) developed for this project, consists of a radio with a radio interface to the MRTU encoder and decoder module, a control module, an electronic driver, solar power supply and the pole-mounted breaker itself.

2.2 The role of the master station.

To succeed in the effective distribution of electric power, a remote control unit is essential, and therefore the need for a centralised control centre is indisputable. From the control centre, information regarding the status of all breakers is monitored and processed. This contributes to obtaining a complete view of the system as a whole.

This would also be the venue where the telecontrol master unit must be installed in order to ease data processing and to determine load trends and graphs of feeder currents and line voltages. The main function is to provide control over all the breakers. This enables the energising and de-energising of power lines, according to the need at that stage.

Figure 2.2 shows how the central master station operates with the MRTUs, by using one operator to control a certain domain of stations and pole-mounted breakers.

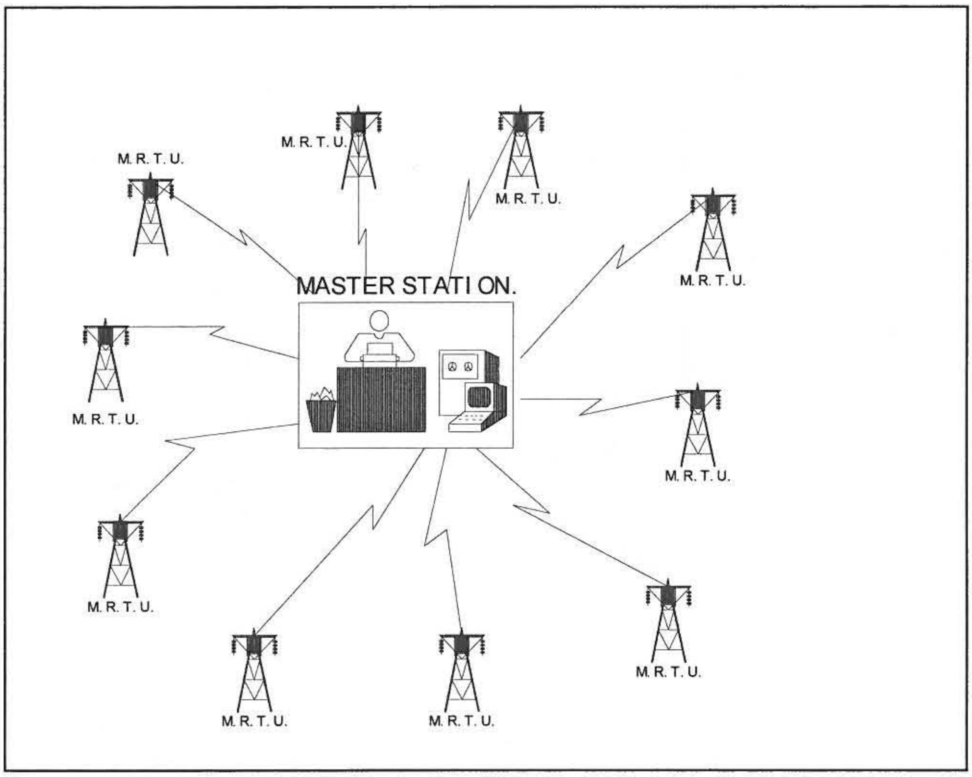


Fig. 2.2: Schematic layout of master station with several modular remote terminal units (MRTUs).

2.3 Remote unit accessories.

All communications between the modular remote terminal unit and its controlling central station are through secure digital codes transmitted over VHF radio channels. This helps to eliminate dependence on expensive leased telephone lines or other communication methods. The modular remote terminal unit (MRTU) provides both discrete and analogue functions, as well as control. The input portion of the unit reports on the status of electrical equipment such as the state of breakers, the loss of power to the unit and other events. The output portion of the unit provides relay contact outputs that can activate or deactivate electrical breakers.

Energy storage is necessary for remote or free standing systems during sunset, night-time, sunrise, inclement weather, or a series of cloudy days. The best suited and most common storage device is the electrical storage battery. According to Mantell [8, p. 5] the battery was one of the first practicable sources of electrical energy developed. Batteries are inherently DC devices and, for some applications a solar array and battery storage system is employed to provide power directly to the load without the use of a power inverter.

A point of great concern is the hazardous effect of lightning on these units. As the destructive effect of lightning cannot be ignored, a considerable amount of attention was given to methods of protection to ensure that the units are protected against lightning discharges as far as humanly possible.

2.4 Computer languages.

According to Strock [20, p. 212] various programming methods have been classified, generally with respect to how similar they are to human language, for example:

- Machine Language: The operator of the system must master the complicated machine language before programming the computer. The operator programs the computer by using coded numbers to indicate the operation to be performed, and where to take or place the data for that operation.

- Assembly Language: Here the computer helps to program itself in a "compromise" with the operator. Mnemonic (easily remembered) assembly language words are converted by a special computer program, so that a given command can become a machine language word that can be re-entered into the machine as a command.

- High Level Language: A more complex computer program compiles one or more machine language words from a certain human language operator input, and outputs them for re-entry as commands.

- Telemetry Language: This is a high-level computer language for use by the telemetry technician or engineer. A computer program is available to convert this to machine language to control the telemetry equipment and telecontrol data processing.

2.4.1 Language encoding.

Sometimes the data format is changed for purposes of transmitting the data from one point in the system to another. When this is the case, the code converter at the transmitting end is called an encoder, and at the receiving end a decoder.

The inefficiency of using a channel for each individual signal, led to the use of a message structure that includes system and station addresses for transmissions between the central and the remote stations [3, p. 13-7]. This has the advantage that more than one message can be transmitted over one single channel, in different message words.

Digital encoding of such messages appeared to be the most appropriate strategy [3, p. 13-8].

This provides maximum consistency with the aims of minimising the channel bandwidth requirement and providing the simplest hardware to effect the operation demanded of the remote station.

Telemetry languages are mostly used in larger multi-user systems that can accommodate concurrent real-time operation, program development, and general data processing. From a telemetry user's viewpoint, multi-user systems are faster and easier to learn. The characteristics of such systems are described below.

2.5 Characteristics of multi-user systems [20, p. 215].

☞ Real-time Response: Responding to an event or interrupts from the telecontrol front end involves more than recognising that something has happened. A response may include simply storing data, or it may involve initiating a complex chain of tasks. The systems, working on telemetry language, reduce the overall response time by minimising the time between recognition of an event and response to it. The result is a highly responsive real-time system.

☞ Multiprogramming: Multiprogramming is implemented to allow higher-priority tasks to pre-empt lower-priority tasks when they are using memory that is needed. This means that dead-time intervals are used by lower-priority tasks. Therefore response time is improved, and the number of events that can be handled at peak times is increased.

☞ Priority Scheduling: Task scheduling is primarily event-driven, based on the software priority assigned to each active task.

☞ Task Protection: Individual task and executive protection are provided, as well as selective access to different areas of sharable libraries and data areas. Selective access options include read and write, read only, and no access.

2.6 Computer message exchange

For the sake of clarity, three types of message exchange (as found on the most common telecontrol computer systems) are shown below [20, p. 225]:

- Controller to Terminal: Called a "receive command"; the terminal (Master Station) may receive up to thirty-two bit words and must respond with a status word.

- Terminal to Controller: Called a "transmit command"; the terminal must transmit a status word and data words.

- Terminal to Terminal: Called a "terminal to terminal transfer command"; the controller first designates the receiver and issues a second command word to designate the transmitter. The transmitter responds with a status word and data words. The receiver answers with its own status word.

2.7 Data word protocol organisation

The command word, which could be a data word or a status word, includes command synchronisation (as used by MRTU's), and according to Strock [20, p. 226] it is followed by bits of information. The last bit is reserved for parity.

Data words have a simple structure and there are no restrictions on the data transmitted. According to Strock [20, p. 204] the standard requires that the most significant data bits be transmitted first and that any unused bits be transmitted as zeros. Status words are issued by MRTUs as transmission or acknowledgment signals. The typical format shown in figure 2.3, is used to signal the controller that the command has been received, and can be executed. The complete protocol format used by this system will be discussed in detail in chapter 3.

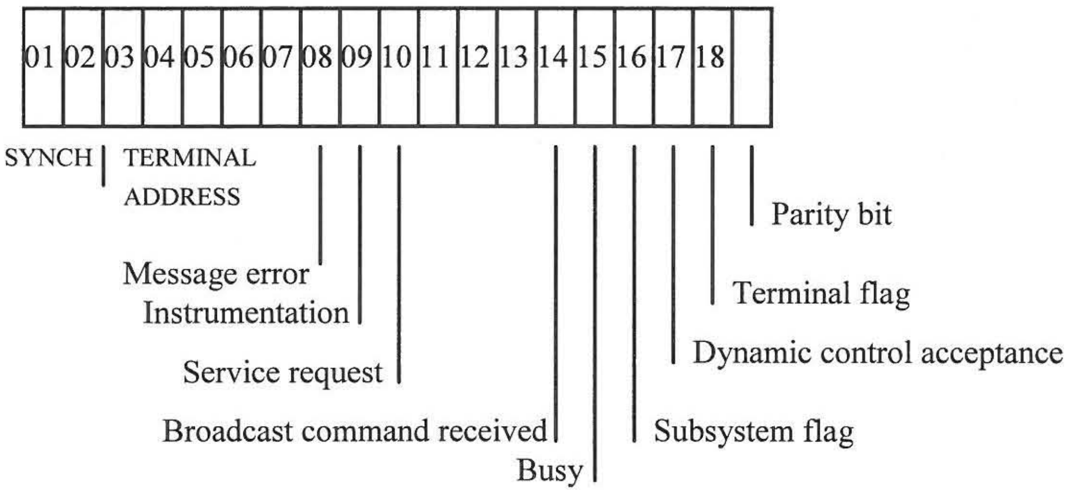


Fig. 2.3: Example of a typical status word. [20, p. 205].

2.8 Telecontrol software.

In the typical computer system, the computer is in charge. It requests data when all previously assigned tasks have been completed. In the case of the telecontrol/computer system, the data stream cannot be controlled by the computer. A multiplexer at the MRTU generates a frame synchronisation pattern and then scans a frame of data, each measurement of which is quantified and output serially as a word. On completion of a frame, another frame synchronisation pattern is generated immediately, then another frame of data. Whether the data are to be entered immediately (in real time), or later by means of playback, the data words occur in the same continuous sequence, interrupted only by periodic frame synchronisation patterns.

Telecontrol or telemetry software is engineer-operated, and does not require knowledge of a confusing computer programming language. Once a system is configured, simple operation can be learned by an operator or engineer much more easily than the operator can learn to operate mimic boards (patch panels) and controls of manually controlled systems.

2.8.1 The control centre.

At the control centre, the master station functions as the device from which all controller commands and information are sent out and stored. In order to accommodate the power system network, the control responsibilities are divided into manageable areas. The controller makes use of operator workstations, in order to monitor and control the power network.

Recent developments have led to the widespread introduction of workstations with full graphic processing capacity. These powerful workstations are now finding their way into energy management systems (EMS), opening a host of new applications in the power system control. Visual display units are particularly important in the design of the operator machine interface for an EMS.

The power system control is achieved by means of workstations, with graphics-display-screens, each equipped with a mouse. The operator communication concept permits transparent representation with window techniques and rapid, simple operation. Commercially available standard software opens up completely new possibilities.

The following brief introduction to LAN Manager has been compiled using information from the Administrator's Guide, Microsoft Lan Manager [11, p. 1-34].

Applications from the fields of office automation, planning and communication can be integrated into a control centre. Examples of these are text processing, spreadsheets, business graphics and electronic mail. All this can be directly integrated into the control room workstation. It is possible to connect one or several PCs to the system by means of the office LAN, which takes over these additional tasks. With LAN Manager, instead of passing a floppy disk from person to person, one can access and share all the information without leaving the workstation.

LAN Manager is a network operating system for a *local area network (LAN),* a group of personal computers with network adapters, connected by cable, that can communicate with each other and share files and printers. The network is made up of workstations and servers. A workstation is a computer that uses information and equipment on the network, and can be grouped into domains. Servers are computers that are used to share files and other equipment such as printers and loggers. With LAN Manager, resources can be shared with users in an organised, efficient way. Any computer running MS OS/2 can act as a LAN Manager server.

Whenever the computer is running, the user has the LAN Manager software running, and starts NetWare connectivity only to access a file or printer on the NetWare network. If the workstation has the Windows environment, the user can use the Windows interface to connect to directories and printers.

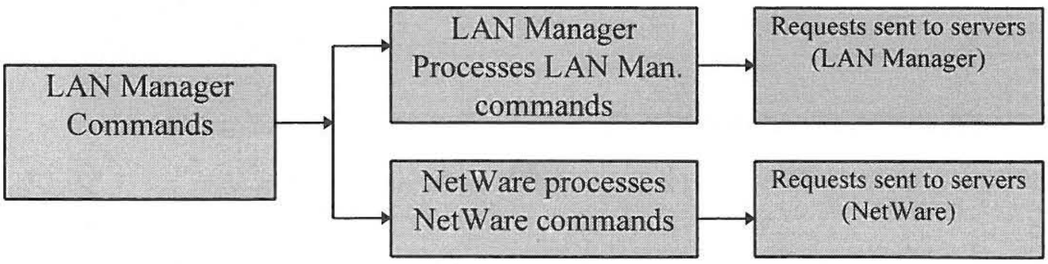


Fig. 2.4: LAN Manager and NetWare command process.

2.9 High voltage switchgear.

The high voltage switchgear is used for switching and protection of the power network. It is driven and monitored by the telecontrol unit, consisting of computer hardware and software. This unit uses computer languages and messages in order to provide SCADA to these switchgear, as described in sections 2.1 - 2.8.

2.9.1 The pole-mounted breaker.

For the protection of power lines, most pole-mounted breakers have the facility of auto-reclosing. If the fault is permanent, the recloser locks out after the preset number of trip operations. The breaker must then be manually reset to restore operation [10, p. 2]. A typical illustration of a pole-mounted breaker is shown in figure 2.5:

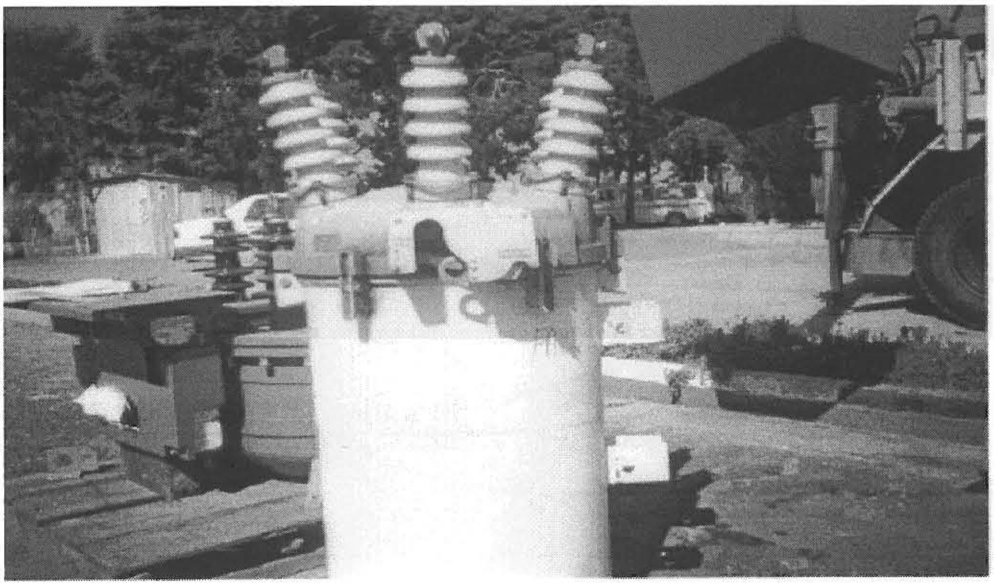


Fig. 2.5: A pole-mounted breaker.

2.9.2 Sectionaliser.

Automatic line-sectionalisers isolate permanent faults and confine outages to small sections of a distribution line. A typical illustration of a sectionaliser is shown in figure 2.6.

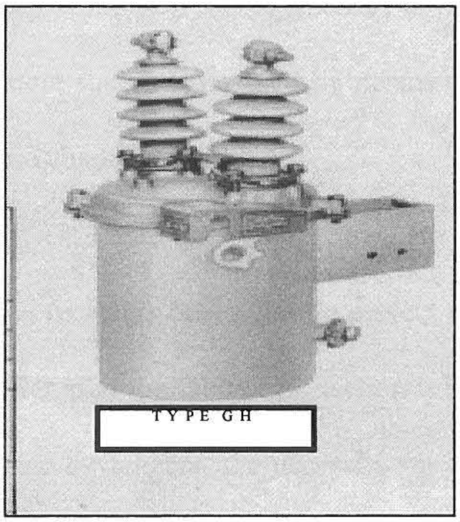


Fig. 2.6: Illustration of a sectionaliser [10, p. 18].

2.9.3 Air-break switches.

Air-break switches are used for flexible, economical sectionalising and interconnecting of feeders. A typical illustration is shown in figure 2.7.

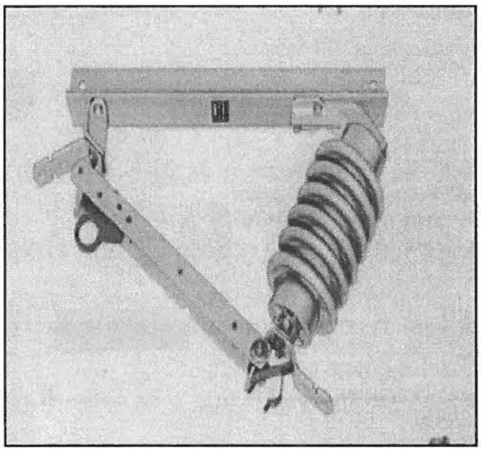


Fig. 2.7. Air-break switch [10, p. 14].

2.10 Conclusion.

Computer based Supervisory Control and Data Acquisition Systems (SCADA) are quite commonly used for power distribution management. Communication from the central control centre to the remote station is enabled by means of a modular remote terminal unit (MRTU) and a radio channel.

High voltage switchgear, such as reclosers only serve to protect the power lines, and cannot automatically restore power after the faulty line section is repaired. In order to have SCADA on this high voltage switchgear, the necessity for a master station and remote units are beyond all dispute.

A master station, operating with multi-user systems and computer languages, with specific protocol can, with the aid of LAN functions, contribute to an effective medium to fill the need for supervision on high voltage systems. As computer technology advanced, these improved operating systems enabled several users to share the same source of information.

The general concept is that the digital inputs, such as status information and alarm signals, the analogue inputs and the control functions are cabled to the input/output units of the MRTU. These signals are multiplexed and transmitted by means of a protocol converter, in the format of a suitable communications protocol to the control centre.

Telecontrol software is engineer operated, and the computer does not control the data stream. The actions performed are dependent on the operator's decision, and not by means of the computer system. The computer only acts as a tool to perform certain tasks. The remote-to-master interrogation and communications must consist of status words to minimize channel bandwidth requirements.

The concept of modular software written in high-level programming languages makes it hardware independent. This is essential to overcome the problems caused by the fast innovation cycles that digital hardware is subjected to. This approach ensures compatibility of hardware and software for system extensions and spares delivered, even years after the original system has been commissioned.

2.11 Personal involvement.

A control centre exists for the use of distribution and reticulation SCADA units, but no reclosers or rural feeders were controlled and monitored at this stage. A temporary test unit was assembled to be tested on the existing radio network.

The author used and studied different computer languages in order to explore a unit adaptable to communicate to the PDP-11 computer that was used at the master station. After various unsuccessful attempts, the author decided to assemble a unit with a similar word protocol as that which was used by the PDP-11. A Spectrum MRTU was assembled, working on its own channel to the control centre. Multifold database configuration was done at the PDP-11, in order to get the slave (MRTU) communicating with the master station.

Unfortunately, protocol problems forced the need to look at other units. Eventually the Spectrum was replaced by an Intrac 2000 store and forward basic module. After various unsuccessful attempts, the protocol problem was solved by software and hardware modifications.

The author arranged with Motorola staff for a sample basic module to be used. This was combined, with a self developed radio interface, control module and other electronic components. After frequency settings had been changed, a standard mobile radio was used for communication purposes. A temporary unit was assembled, which was used for communication tests to the PDP-11 on a separate channel. The communication to and from the temporary unit worked satisfactorily. This solved the communication and protocol problems.

As this was solved, the author combined the radio communications with the Free State Region's communication channel, and repeated the tests with satisfactory results. This resulted in the assembly of a complete MRTU unit, as described during this document.

Rural network skeletons were drawn by the author on the PDP-11, making use of the PDP-11 CAD program. A complete database program, combining the MRTU data with the skeleton was completed, in order to give a visual image of the alarm states and conditions. The prototype RTU, as well as the PDP-11 master was tested and worked very well.

Unfortunately, the PDP-11 was replaced at that stage by a new, open-ended unit, called the Sentinel. This set the project back at that stage. The software of the new master station was completely different to that of the PDP-11. Instead of Micro/RSX, the Sentinel used OS/2, Poly PM/2, and a Spescom CAD program. The two existing operator workstations were also replaced by 7 new operator workstations. As the commissioning and installation of the new master was the author's responsibility, the MRTU project was delayed for a while in order to complete the commissioning of the new master station.

The Sentinel master station worked on a LAN. This could be used to the advantage of the pole-mounted breaker project, because the author now had the facility to combine the pole-mounted breaker telecontrol with the distribution telecontrol master stations.

The software database configuration for the Distribution and Regional substations was completed before any further software tests could be carried out on the pole-mounted breaker unit.

After the LCU, Server and workstations were commissioned and tested, software and hardware changes were implemented to allow the assembled MRTU to be tested. The PDP-11 was decommissioned, with still no pole-mounted breaker units working in the region .

The whole process was started from scratch again, and protocol changes were requested from the suppliers of the Sentinel. This was tested, and after minor changes the prototype MRTU communicated with the Sentinel. The software changes at the LCU, the Server and the MRTU, which was carried out resulted in an operational prototype MRTU. Appendix A shows a block diagram of the LCU software, as configured for this project.

The database configuration at the server was edited, and linked to the skeletons that were drawn especially for the test MRTU.

This is discussed in paragraphs 5.2.6 and 5.2.9. In chapter 2, a brief summary of computer messages, data word protocols, telecontrol software, the LAN and High voltage switchgear, as investigated and used by the author, is explained, to indicate why and how this supervisory unit was developed.

CHAPTER 3

METHODS AND TECHNIQUES

3.1 The SCADA system.

Any SCADA system must consist of at least a master station, remote units and a reliable communications network, as shown in figure 2.1. Various types of remote units were considered, which included the following types:

- ✓ *Spectrum Teleranger.*
- ✓ *Motorola Intrac 2000 Modular remote terminal unit.*
- ✓ *Advance Control Systems MPR 7085 Remote terminal unit.*
- ✓ *IST Micro-RTU*

The *Advance Control Systems MPR 7085 RTU* and the *IST Micro-RTU* could not be adapted to the protocol of the master station at that stage, and was also too expensive for this project. Therefore these options were discarded.

The Spectrum Teleranger seemed to be very competent compared to the Motorola Intrac 2000, but as the protocol to the master station also lacked at that stage, the only remaining option was the Intrac 2000.

The disadvantage of the Intrac 2000 was that no complete unit existed, and a unit had to be developed and assembled by making use of various modules and components. The advantage was that a reliable unit was developed, making use of available modules. This saved in staff training, and also in purchasing additional spare modules and radios for maintenance purposes. The possibility that Rural substation RTU's will be replaced by ERTU's, provides a sustained supply of MRTU's to be dismantled. These can be used as Pole-mounted MRTU's, with vast economic benefits.

The remote units, or pole-mounted telecontrol units in this case, consist of Intrac MRTU basic modules and control modules assembled with other components, as shown in figure 3.1.

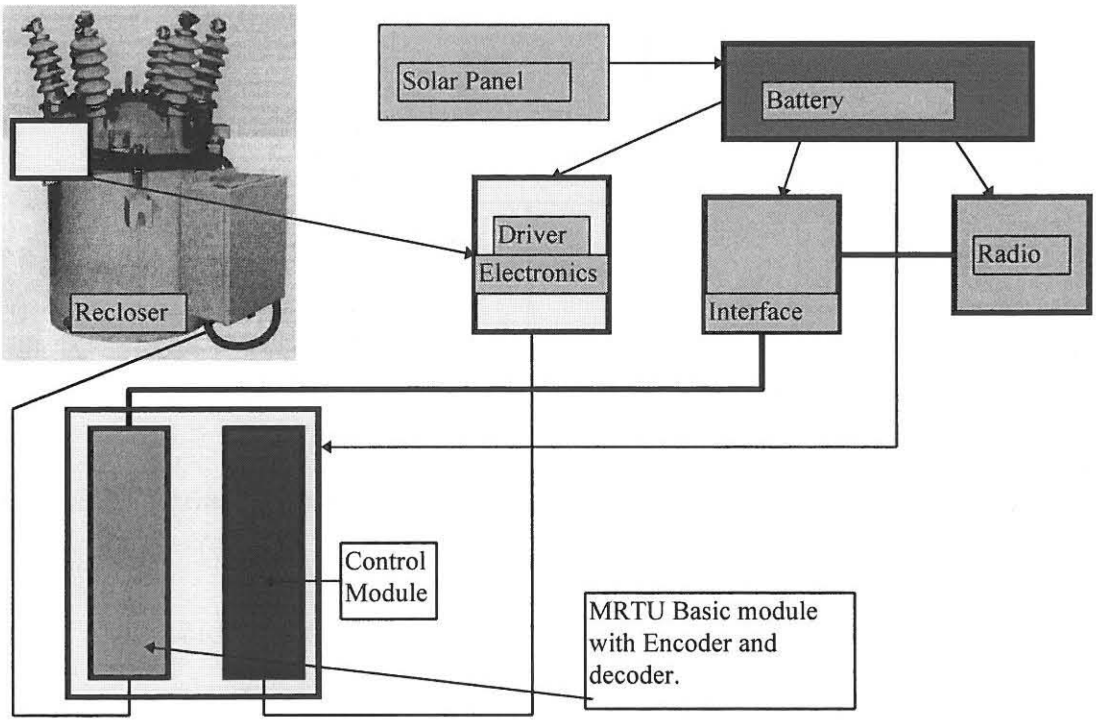


Fig 3.1: Block diagram of the remote pole-mounted telecontrol unit.

The master station, which in this case is computer-based, contains an open, fully integrated control system. The concept of open systems architecture inherently offers an increased control system availability and improved upgradeability. With the rapid advances of technology in this field, the necessity to ensure that the MRTU will adapt to most modern open systems was seriously considered.

The Intrac 2000 modular remote terminal unit (MRTU) is a multi-purpose unit, and is used to monitor and control functions at remote locations. It can communicate with both central and other modular remote terminal units (MRTUs) by means of securely coded messages, superimposed over FM radio, microwave transmissions, or over wire-lines. The messages transmitted by and received from the MRTU are constructed of code words as shown in figure 3.2. (Visualised at the Motorola test set).

Station address	System address	Data	Security

<—————— ± 81 ms, 32-bit word ——————>

Fig. 3.2: Format of the MRTU message.

Each code word includes an address identifying the specific transmitting MRTU. The MRTU address has two parts: the system address and the station address.

The MRTU is based on the 68HC11 microcomputer. It consists of EEPROM memory, analogue-to-digital converters, serial peripheral interface (SPI) and serial communication interface (SCI). The MRTU also contains a 32k EPROM and 8k RAM, slots for external memory expansion, two momentary (operates once, until reset pulse received) relays, eight discrete inputs and four double-ended analogue inputs [12, p. 1].

3.1.1 MRTU word encoding and decoding [12, p. 5].

The code word encoder and decoder are the heart of the MRTU basic module, and these are situated in the MRTU basic module at the control centre. A schematic layout of the MRTU is shown in figure 3.3.

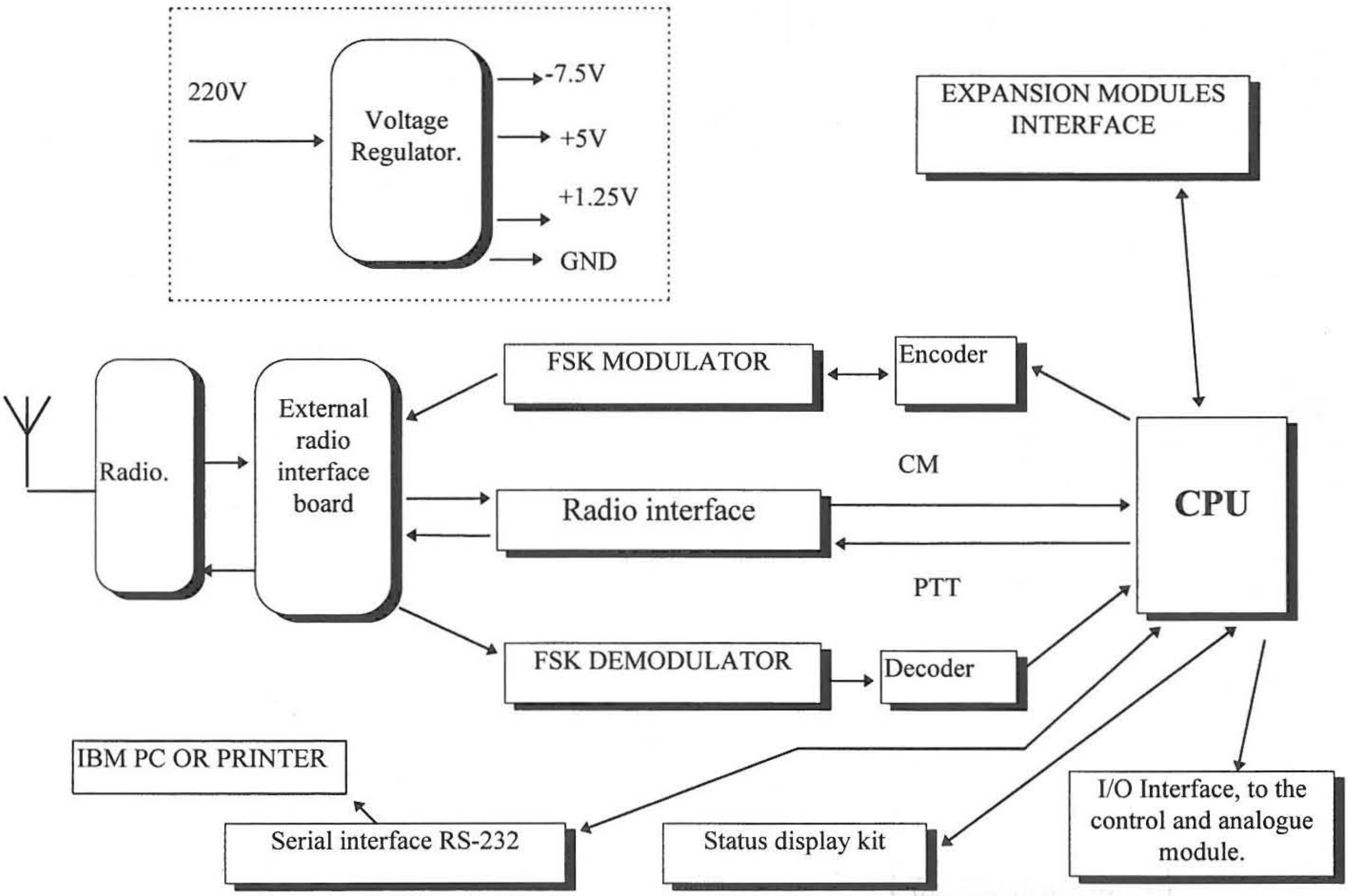
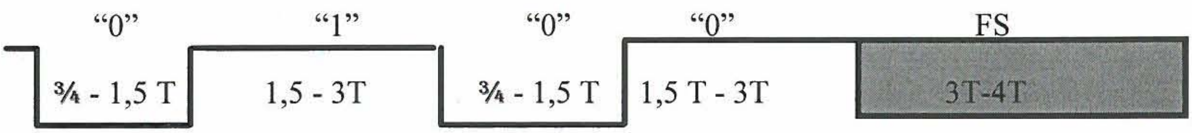


Fig. 3.3 Schematic layout of MRTU basic module. [12, p. 5].

The word decoder shown in figure 3.3 transfers the bits received from the FSK demodulator serially to the expansion modules interface, via the CPU, while adding the BCH code bits and frame synchronisation pulses.

The word encoder converts the serial information from the CPU into 26 bits. This is done after checking the validity of the serial word and frame synchronisation, bit count, number of bits less than 1/2 T duration, and BCH codes. The data is then transferred to the FSK modulator for transmission by the radio, as shown in figure 3.3.

This data is then transmitted to the radio. The output is pulse duration modulated, where the logic zero is of 1T duration, logic one of 2T duration and the frame synchronisation pulse of 4T duration (T=1,67 ms.), as shown in the FSK timing diagram of figure 3.4.



Data out: "1" = 900 Hz. "0" = 1500 Hz T = 1,67 ms.

Fig. 3.4: FSK timing diagram.

The MRTU basic module is illustrated by the photograph in figure 3.5.

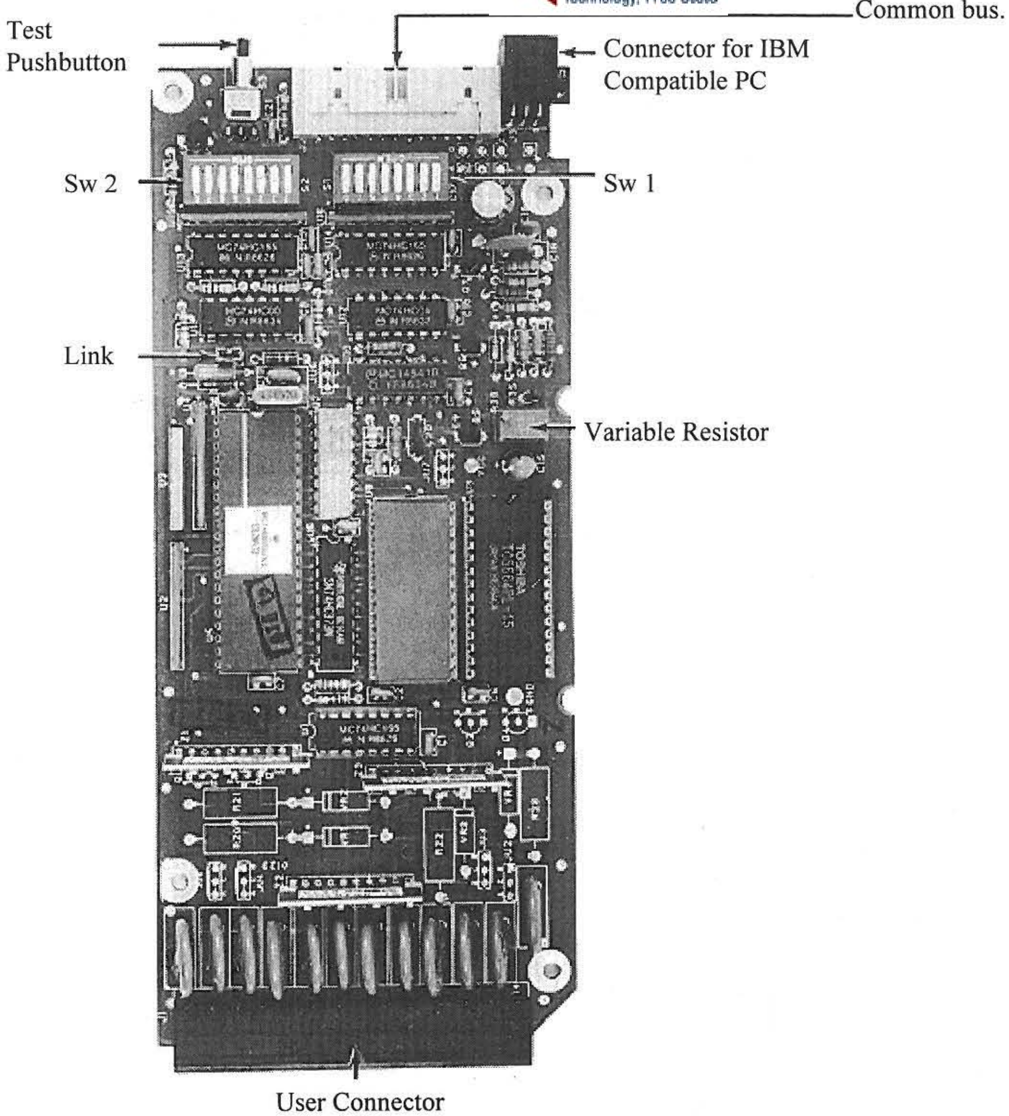


Fig. 3.5: Photograph of MRTU basic module. [12, p. 6].

The test button in figure 3.5 is used for a forced data transmission of the MRTU status. SW1 and SW2 set the MRTU operating voltage and modulation frequencies respectively. The user connector connects the pole-mounted breaker auxiliary contacts to the MRTU. The connector for an IBM compatible PC is used for field testing, and configuration downloading. The common bus connects the MRTU basic module to the control module (see figures 2.1 and 3.3).

The message format (see figure 3.2) consists of a 32 bit message, starting at bit 0, and functions as follows: [12, p. 10].

- Bit 0; Set marker bit.
- Bit 1 - 9; Station address.
- Bit 10 - 11; System address.
- Bit 12 - 14; Code word group address.
- Bit 15; "0" = Remote unit, "1" = Central master station.
- Bit 16 - 23; Data.
- Bit 24; Power failure.
- Bit 25; Change of state.
- Bit 26 - 30; Bose Chadhuri security bits.
- Bit 31; Parity bit, ending with the frame-synch pulse.

3.1.2 MRTU radio channels.

The MRTU functions on the existing mobile-radio system, which covers approximately 80-90% of the region at a level of -113 dBm or better. Each repeater is connected to the regional control centre by an independent channel.

Different controlled regions are accommodated by grouping the communications of only the supervisory controlled stations at the control centre, and not all communications at the group repeater. This is done by combining the individually received MRTU radio channels through store and forward repeaters, into 4 groups, via 4 central interface units to the main computer at the control centre.

3.1.3 The MRTU capacity of the system.

The structure allows several users to share the same communication channel and each of them utilises its own system. The systems are distinguished from one another by a unique system address for each system; the station address identifies each MRTU in the system. The address capacity allows four systems (system address 0-3) each with 512 station addresses. The analogue address (identification address of analogue module) is equal to the station address + 1. The total number of MRTUs could be as large as (512 x 4) = 2048 remote units per master station, as shown in figure 3.6.

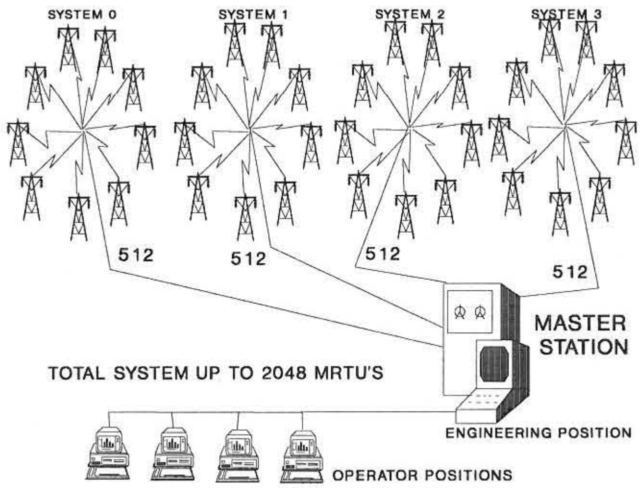


Fig. 3.6: MRTU capacity of the system.

3.1.4 MRTU hardware.

The MRTU can monitor status inputs and analogue inputs and can provide relay outputs which are used for control functions.

The MRTU provides hardware for Frequency Shift Keying (FSK) encoding and decoding, Push To Talk (PTT) and Channel Monitor (CM) with an interface for radio communication.

3.1.5 The MRTU position.

Since remote units are situated anywhere on a power line, the units were installed out of reach of malicious damage. The units were installed inside separate containers mounted on the same poles as the breakers. Care was taken to prevent water and dust from entering the container.

3.1.6 MRTU installation and dismantling.

The units are self supporting in terms of the power supply. Solar panels and backup battery supplies, which can easily be installed or removed if needed, are used. A fixed bracket was fitted to the pole to facilitate the installation and dismantling of a MRTU unit. Plug-in cables are used for the breaker and solar panel to ease the process of dismantling.

3.2 The control module.

This module receives execute code words from the basic module through the common bus, as shown in figure 2.1. It contains four relays, grouped in a control port, which can operate in four modes:

- General mode: The relay will operate as long as it is activated.
- Latched mode: The relay will latch and must be reset after operation.
- Momentary mode: The relay will operate for a specific preset time only.
- Common latched mode: The relay will latch at a certain specified state upon power or communication failure.

The MRTU was configured at "momentary mode" by the author, for the purpose of this project. For a detailed explanation, refer to Appendix C.

The Control output module performs three functions:

1. Activate relays upon receipt of an execute code word from the basic module.
2. Preset latched and common relays.
3. Reset relays with startup.

3.3 The MRTU power supply.

As with any electrical or electronic circuitry, the modular remote terminal unit (MRTU) requires electrical energy to function. Due to the location of the Pole-mounted Breakers (PMBs), voltages below 380 Vac are generally not available. A few options were considered, but it was found that each remote terminal unit had to be dealt with individually.

3.3.1 Solar power.

Radiant energy from the sun enters the earth's atmosphere at a rate estimated to be 1,3 kW/m² [17, p. 16]. Part of this energy is reflected by the atmosphere, part is absorbed by the atmosphere itself, and the remainder (about 1kW/m²) reaches the earth's surface.

Photovoltaic energy can be provided by solar cells which convert sunlight directly into electricity. According to Raynham [17, p. 16], Roberts [18, p. 4] and Myers [14, p. 288] commercial types of solar cells are available with conversion efficiencies ranging from about 4% to 28%.

Most photovoltaic systems utilize voltage regulators to stabilize the voltage within required limits to prevent overcharge and gassing of the battery. The voltage regulator dissipates the excess available power.

TEST MEASUREMENTS DONE BY THE AUTHOR ON THE MRTU WERE RECORDED AS FOLLOWS:

Squelch current of radio = 95 mA.

Idle current of electronics = 15 mA.

Total idle current of the system = 110 mA.

Transmitting current of the radio = 4,9 A.

Electronics operating current = 75 mA.

Motor current = 1,63 A.

THE TOTAL POWER ABSORPTION WAS CALCULATED AS FOLLOWS:

Total operating current = 6,605 Amp.

Operating voltage = 13.5V.

Total power consumption = 89,16W.

From statistics received, it was calculated that the average number of pole-mounted breaker operations per annum is approximately 16. This is less than two operations in a period of one month. For the purpose of this research, the worst case criterion of 5 operations per day was used.

The maximum power needed will amount to 89,16 W during each operation of the recloser.

Solar panel specifications:

V_{oc}=21.3 V, I_{sc}=3.15A, P_{max}=52 W, V_l=17.3 V, I_l=3 A, I_{nom}=3.10 A.

The solar panel employed is able to supply a constant 52 watts during sunny conditions, and has proved to be very efficient and successful, even under cloudy conditions. Therefore, a smaller solar panel (eg. 25 watts) will function just as efficiently and may prove to be a better choice for future use.

The solar panel cannot deliver the peak output power as calculated. For this reason, and also to ensure operation in adverse weather conditions, it is backed up by a battery. The battery used is a 24 A/h lead acid battery, and it can operate for more than 7 days without receiving any energy from the solar panel. When the voltage falls below a presetted value, the MRTU sends an alarm to the control centre, informing the technicians that the battery has been discharged.

3.3.2 Cable from power source.

On locations where there is a nearby 380/220 Vac source available, the cost effectiveness of installing an armored cable from that source to the MRTU can be investigated, as this option was working well during tests. A suitable 220 Vac to 13.5 Vdc power supply with a minimum continuous current of 1 ampere can be used. This will enable the unit to operate efficiently. Since few of the pole-mounted breaker sites had this facility, this option was not implemented during the project.

3.3.3 Transformer power.

The option to make use of a transformer connected to the power lines as a source of power was also tested. The cost of these transformers and power supplies can, however amount to more than the cost of the MRTU itself.

3.3.4 PMB internal electric power.

Some of the reclosers, such as the McGraw Edison 10001-8, require 15-18 Vdc on the electronic controller board to operate [10, p. 27]. The power source that generates this supply can be used with great effectiveness for trickle-charging of the MRTU battery and can reduce expenses and unnecessary additional equipment. Unfortunately, very few reclosers with this option are available, but this power source can be implemented selectively, depending on the recloser type.

3.3.5 PMB VTs and CTs.

Some reclosers, such as the McGraw Edison 10003-E, make use of internal 600 V voltage transformers for the trip capacitor charging coils [10, p. 7]. This voltage can be used, and stepped down to 220Vac, with the help of a small step-down transformer coupled to the control box. The internal bushing current transformers, which are mounted under the head, can also be used as a source. This energy can be stored in a battery, and can supply both the telecontrol and the recloser equipment. The disadvantage of this option is that the pole-mounted breaker will have to be untanked, and requires modifications inside the recloser, which can hamper the installation process. This must be avoided in order to standardise the installation process. Since the aim is to avoid modifications within the reclosers as far as possible, this option was not implemented.

3.3.6 Voltage regulators.

Fink [2, p. 7-63] stated that storage batteries can be charged at any rate that does not produce excessive gassing or high temperatures. They can also be float, or trickle-charged, when they are continuously connected to an electrical system. To prevent overcharging, the current should be regulated. According to Myers [14, p. 299] and Roberts [18, p. 30], most photovoltaic (PV) systems utilize a voltage regulator to maintain the voltage within required limits to prevent battery overcharge and gassing.

Charge regulators are designed to provide protection for the solar system battery. Such a regulator must provide protection against overcharging the battery by disconnecting the solar panel when the battery is fully charged, and also by disconnecting the load when the battery becomes excessively discharged. A suitable regulator (BPRS-L), with the following characteristics was used:

- ✓ Nominal voltage: 12 V; charge cutout voltage: 14.6 V; Module reconnect voltage: 13.0 V.
- ✓ Load disconnect voltage: 11.1 V; Load reconnect voltage: 12.0 V; Cycling delay on module reconnect: 10-15 min.

3.4 Radio communication.

The requirements for a reliable radio to be used with the pole-mounted breaker remote units are as follows:

- Operate on 12 Vdc negative ground power.
- Time-out timer. (This function is essential to prevent the radio from overheating and possible damage in the case of MRTU faulty or lock-up condition, as occurred in the past.)
- Synthesized, wide band operation. (Spare crystals are expensive for channel frequency changes.)
- Multiple coded squelch capability. (Squelch can be opened at presetted signal strength.)
- Field programming capability. (Easy programming feature.)
- Must comply with military specifications for shock and vibration.

The choice of radio to be used for telecontrol units is very large, since various makes and models exist, each having excellent specifications. The aim was to make use of radios with synthesizers in order to avoid endless searching for suitable crystals when replacing radios or changing frequencies.

Since the MRTU basic module that was used was supplied by Motorola, a 16-channel synthesized Motorola M200 radio and interface were used to match with these units. The main advantage of this radio is the availability of a time-out timer. This prevents the radio from continuously transmitting and occupying air traffic. This radio exceeds all required specifications, and is very reasonably priced.

The M200 radio is widely used in VHF and UHF applications, and uses the Armstrong method, in which FM is achieved by a combination of DSB suppressed carrier and phase modulation. Fig. 3.7 shows a block diagram of the Armstrong method of indirect frequency modulation.

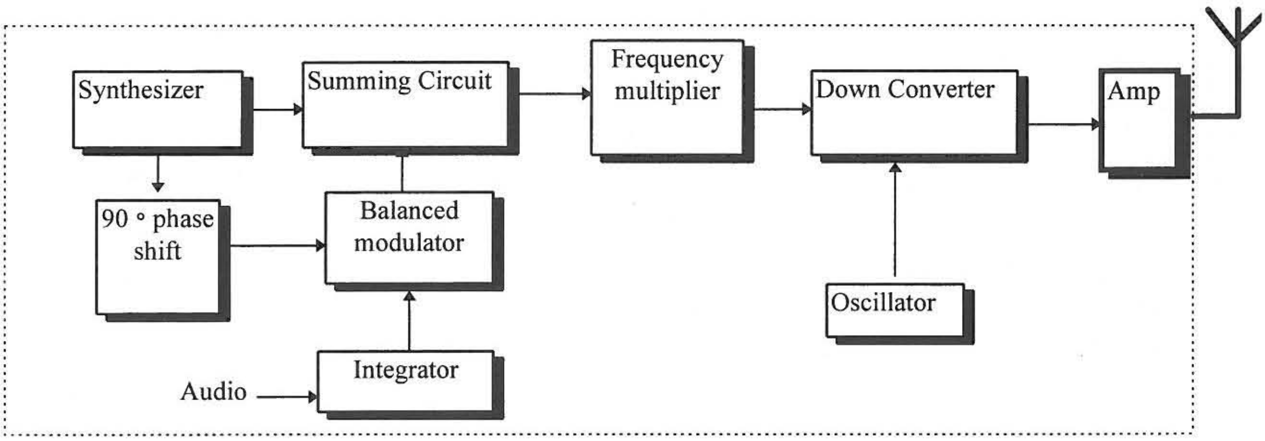


Fig. 3.7: Radio with Armstrong method of frequency modulation. [4, p. 120].

3.5 The antenna.

The antenna used by the radio forms an integral part of the MRTU, as any telecontrol system is only as reliable as its communications link with the MRTU.

3.5.1 Effects of ground on the antenna.

As the ground can be considered a reflecting surface, it influences the radiation pattern and other properties of antennas placed near it. The earth has generally been considered a perfect conductor, but it often stops short of this ideal. Therefore, care is taken to make use of a good grounding system. An earth mat can be used where the ground is of low conductivity. Most of the sites where reclosers are installed are already equipped with such an earth mat.

3.5.2 Yagi-Uda antenna.

Experimental tests were carried out by the author ± 30 km from the nearest repeater with several kinds of antennas. The best signal strength of -52 dB was found with a 5-stack Yagi having a gain of 9 dB.

Kennedy [4, p. 310] states that this antenna is relatively directional, and has a moderate gain in the vicinity of 7 dB. It is very compact and because of the folded dipole used, the Yagi offers relatively high gain combined with a fair front-to-back ratio and easy mounting, whilst retaining very acceptable bandwidths and beamwidths. During tests, this has proved to be a very successful choice of antenna.

3.6 Protection.

Lightning has serious destructive effects on electrical and electronic equipment, therefore the best available, and most reliable known methods of lightning protection were used.

Telecommunication apparatus such as radios, telecontrol units, and other sophisticated equipment require lightning protection for several reasons. Frequently they are located high above ground, as with the pole-mounted remote terminal units (MRTU), which are mounted on a pole. In most cases elevated ground is rocky and has a high resistivity. This type of equipment is a likely recipient of lightning strokes. If struck by lightning, the lightning discharge potential cannot be diverted to earth, due to the high resistivity, with consequent destructive effects to MRTU equipment. The reaction of modern equipment to lightning discharges may range from signal fluctuations or false alarms to complete destruction of the equipment.

The objectives of lightning protection are to protect apparatus from damage or loss, to prevent the disruption of essential services, and to reduce the risk of fatality or injury while working on such apparatus. Lightning can damage the electronic equipment in the following three ways;

➡ Direct strike; lightning can strike the antenna, solar panel or cable. The longer the cable, the higher the probability of occurrence.

➡ Radiated strike; cloud-to-cloud lightning generates a horizontal field that induces currents in signal or communication wires. Although the induced currents due to this effect are lower in magnitude, compared to a direct strike, they are significantly more likely to occur.

➡ Conducted strike; one of the most common and damaging, is when lightning strikes within kilometers of the object. This raises the local ground potential, and where the earth resistance is low, large earth currents will circulate in the system.

According to the ERA Seminar proceedings [1, p. 2.6], research over the last 10-year period by British and Japanese telecommunication authorities shows that 99% of all induced surges last for only several microseconds, and the surge currents are quite low. The requirements for successful lightning protection are as follows:

- ✧ The protection barrier should clamp all surges to safe levels.
- ✧ It should survive surges lasting several orders longer than statistically analyzed surges.
- ✧ Internal resistance and stray inductance should be as low as possible.
- ✧ Large currents should be diverted safely to ground, by means of reliable earthing techniques.

Special attention was given to earthing during the course of the project. Several earthing systems are currently in use, but, for the purpose of this project only two types are mentioned.

3.6.1 <u>Protective earth.</u>

Electronic equipment, such as television, radio's and other circuits usually have a reference electronic earth, which is used for functioning the circuit's electronics, and can be seperated by up to a few ohms on certain devices, from the protective earth. One would not want the electronic earth accidentally to be used as a protective earth.

Care must be taken for earthing to be done at one point only. This will also keep the system referenced and also minimize noise.

3.6.2 Neutral point earthing.

Ground-earth is the theoretical "infinite" earth where all currents eventually stray, including those due to lightning. Ground-earth surge-impedance is quite complex, and recent research has found that it varies with time, as lightning dissipates, and can be several times larger than the steady state, measured value [5, p. 20/16]. The surge impedance can rise due to earlier strikes.

According to Laughton and Say [5, p. 20/16], earthing is the process of connecting all metalwork to the main body of the earth. The aim is to convey to earth any leakage of electrical energy to the metalwork, without hazard to personnel or equipment. Neutral point earthing secures a relatively high effectiveness of automatic gear protection and can be used as an earthing method to reference all surge currents to the ground potential, relative to the ground-earth, as showed in figure 3.8. [9, p. 56].

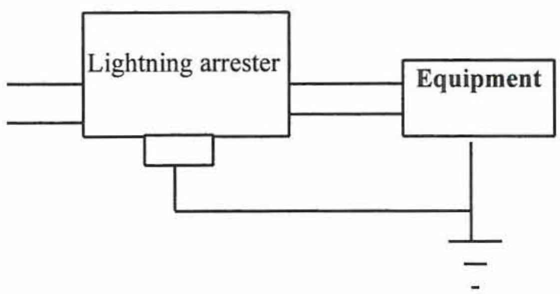


Fig. 3.8: Neutral Point Earthing.

3.6.3 Protective fusing.

Fuses form a considerable part of the protection of the pole-mounted remote terminal unit (PMRTU). Fuses perform two basic functions: the passive function of carrying current during normal conditions in the circuit, and the active function of interrupting overcurrents during fault clearance [5, p. 5-55].

According to Fink [2, pp. 28-33], fuses should have ratings that correspond to those of the parts and circuits they protect. The fuse ratings should be compatible with starting and operating currents as well as ambient temperatures. Current-carrying capacity may vary with temperature, and this should be taken into consideration. Fusing should be arranged so that fuses in branch circuits will blow before fuses in the main circuit.

Fuses are used in both the master and remote units. In the case of the remote unit, fast action fuses are used to protect both the radio and the integrated electronic circuitry. These will prevent the equipment from being damaged in case of short circuits or overcurrent situations.

3.7. Summary and conclusions.

The MRTU multi-purpose unit, communicating by means of coded messages through a radio-channel is a very suitable option. The MRTU capacity appears to be able to accommodate all the pole-mounted breakers in the region.

In order to prevent unnecessary disassembly and modifications on the reclosers, the option of using solar energy has proved very successful. This requires that a solar panel must be mounted on the pole, at a relatively low cost when compared to other methods. The use of solar power on most of these units is recommended where no alternative 220V power source is available.

Any supervisory system, irrespective of design or technology, is as reliable as the communication medium attached to the system. Therefore, in order to have a reliable system, the communication must be of a very good quality.

This is attained by means of reliable radios (such as those used during this project) and antennae and proven earthing techniques. Proper protection (e.g. fusing), can also contribute to extend the life-span of the units.

Although the use of dipoles seems very tempting, bad communications can occur during inclement weather. The use of a 5 stack Yagi as a standard is recommended, as it has proved to be very successful during the experimental period.

The solar panel used during this project can be replaced with a smaller panel for future units, which will assist in reducing expenditure.

3.8 Personal involvement.

Various tests were performed on different units available off the shelf, though none of them was designed for the purpose as required at that stage. After various tests, the Intrac 2000 was chosen.

This resulted in a study being made of the Intrac 2000 word encoding, and thorough testing through to the control centre on a Motorola Test set. The code word was tested to the CIU, the LCU and the OW's, as both MRTU and master station must use the same type of module for satisfactory handshaking.

During these tests the author also tested the MRTU radio channel, and found that a limit existed on the MRTU capacity. This could limit the maximum amount of MRTU's to be connected to the system.

From previous experience on electrical equipment, the author realised that the positioning of such a unit had to allow for ease of installation and dismantling but at the same time had to be robust against weather conditions and possible malicious damage.

Various power supply methods were tested on different reclosers in operation in the Clocolan area. This was done with the assistance of protection staff, distribution officials and electricians, using their equipment and appliances. These tests included the following:

1) The installation of a temporary cable from a nearby power source, with a 12V power supply and a battery.

2) The installation of a spare transformer at one recloser site, with a 380/220 Vac secondary output to the power supply and battery.

3) The internal voltage of the recloser was also measured by the author to be 18 Vdc. Regulated to 12 volt, the battery was charged successfully utilising this voltage.

4) Utilising CT or VT voltages was also considered, but this was not tested or proven to be suitable as a possible power source, because no suitable transformer was available at that stage.

After completion of the tests, the author decided that a more standard source had to be found, as the above mentioned sources were cumbersome and costly. Solar power was therefore considered.

A 52 watt solar panel was tested, and the need for a voltage regulator was found, as the solar panel output rose to 25 Vdc during sunny days. After a standard 12 V / 5A regulator was built, the author found that an off the shelf regulator was available. This regulator had a low voltage LED that was used via a relay, instead of designing a circuit to indicate the low voltage of the battery. Local tests were done, and the solar panel proved to be suitable for this project. A smaller 25 watt solar panel should also be suitable.

Tests on Phillips, Storno and Motorola radios were performed, and the Motorola outperformed other radios as mentioned in section 3.4.

Various tests were done on different antennas, and during experimental tests the author decided on the Yagi-Uda, as explained in section 3.5.

During these tests, the need for suitable protection precautions was realized. Suitable earth, fusing and lightning protection methods were recommended.

CHAPTER 4

COMMUNICATION SYSTEM HARDWARE

This chapter covers broadly the Motorola hardware that was used. It consists of mostly, a summary of relevant parts from the operating manual [12, pp. 1-96] and has been included for reference purposes.

4.1 The central interface unit (CIU) functional description.

The central interface unit (CIU) is situated at the master station, as shown in figure 2.1. It functions as the interface between the encoder and decoder, and the line control unit (LCU). Figure 4.1 shows a Block diagram of the CIU.

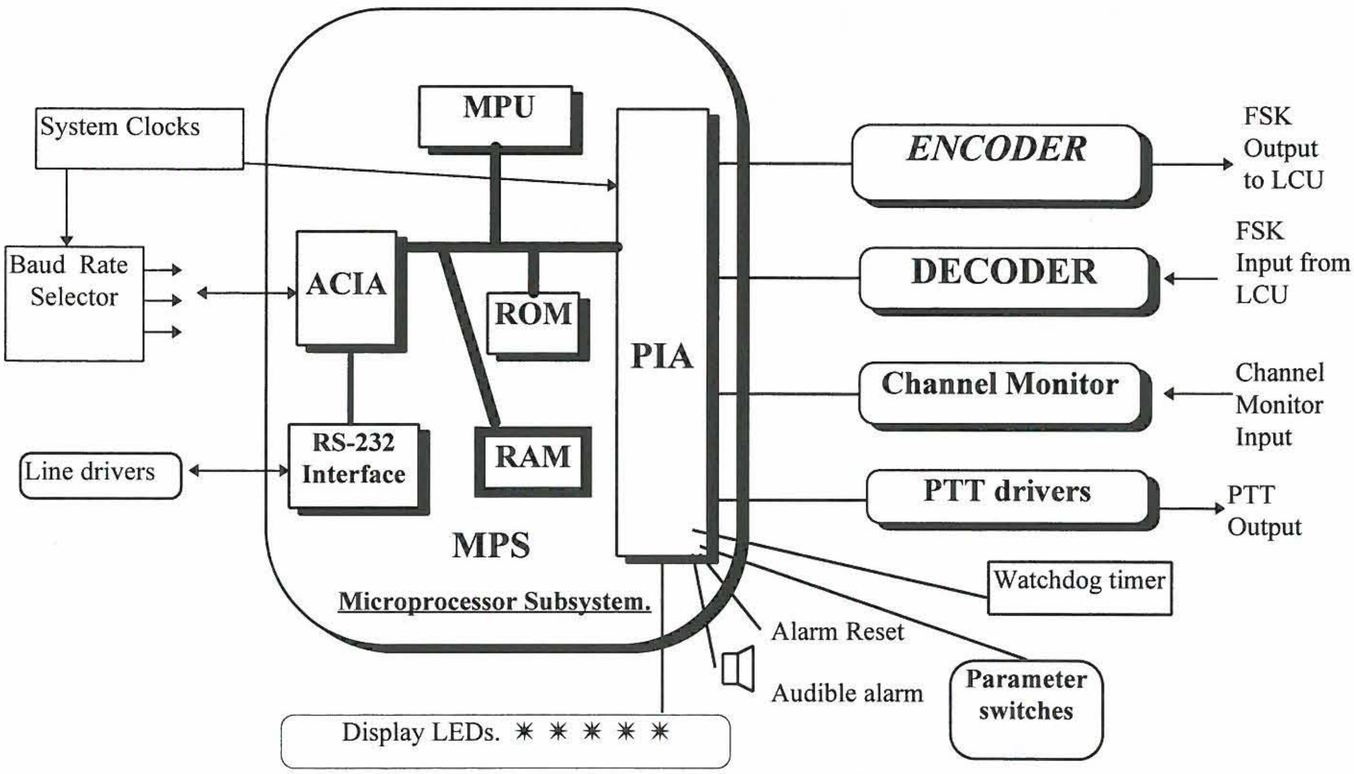


Fig. 4.1: Block diagram of central interface unit. [12, p. 4].

According to Motorola [12, p. 3-4], the CIU comprises three major functional divisions, the microprocessor subsystem, the encoding and decoding sections, and the auxiliary circuits.

4.1.1 The microprocessor subsystem (MPS) [12, p. 3-4].

According to Motorola [12, pp. 3-4], and practical experience on the MPS, a brief discussion of the MPS can be summarised as follows: The microprocessor subsystem (MPS) is the heart of the central interface unit; it interconnects with, and co-ordinates all the other sections of the logic board. The MPS is based on the MC6802 microprocessor unit (MPU), which controls the transfer of all information through the MPS, between the device's peripherals and the MPU. This information consists of control signals, addresses and data. The addresses sent from the MPU select the desired peripheral devices. The data then flows between the MPU and the selected device via a bidirectional data bus. The control signals command the required control functions of the MPS such as the direction of data transfer (read or write) and MPU initialization. The peripheral devices in the microprocessor subsystem are:

❶ ***The Read Only Memory (ROM);*** which includes three integrated circuits, each with a memory capacity of 2048 bytes, containing the programs that control the operations of the CIU.

❷ *The Random Access Memory (RAM);* which provides a working memory for the CIU. It consists of two integrated circuits that together constitute a memory of 1024 bytes. Another 128 byte of RAM is available in the MPU itself.

❸ *The Peripheral Interface Adapter (PIA);* which interfaces the MPS with the communication network, operator controls and indicators, and other circuits required for CIU operation.

❹ *The Asynchronous Communication Interface Adapter (ACIA);* which converts data written into it by the MPU to characters serially transmitted to an external controller, and enables the MPU to recognize characters received from the controller. The ACIA communicates with the external controller via RS-232 line drivers and receivers.

4.1.2 CIU encoding and decoding [12, p. 3].

All communication between the controller and the remote stations is based on the transmission of bursts of code words, via radio frequency or wired communication channels. Each code word is constructed of 32 bits, of which 26 bits convey data and 6 bits are utilized for security purposes, as described in chapter 3. All code words begin and end with a frame synchronization (FS) pulse. The code word employs two basic techniques to encode this data:

⇨ *Pulse Duration Modulation (PDM):* An individual bit, logic 0 or logic 1, is defined in the code word. This is not done by the low or high state of the signal, but rather by the time interval between two consecutive signal transitions from one state to the other, either from low to high or vice versa. The basic time interval for pulse duration encoding or decoding is 1/baud rate and is designated "T". The network uses a baud rate of 600 Hz. T = 1/600 seconds (1,67 ms) defines a logic 0 as a time interval of T, a logic 1 as an interval of 2T (3,33 ms), and a frame synchronization (FS) [a combination of "1" 's an "0" 's] as an interval of 4T (6,67 ms).

⇨ ***FSK Modulation*** - The pulse duration data signal enters the communication channel by way of the frequency-shift keying (FSK) encoder, which converts the data signal to two different audio tones ("mark" and "space") to express the low and high states of the signal.

4.1.3 The CIU encoder [12, p. 5].

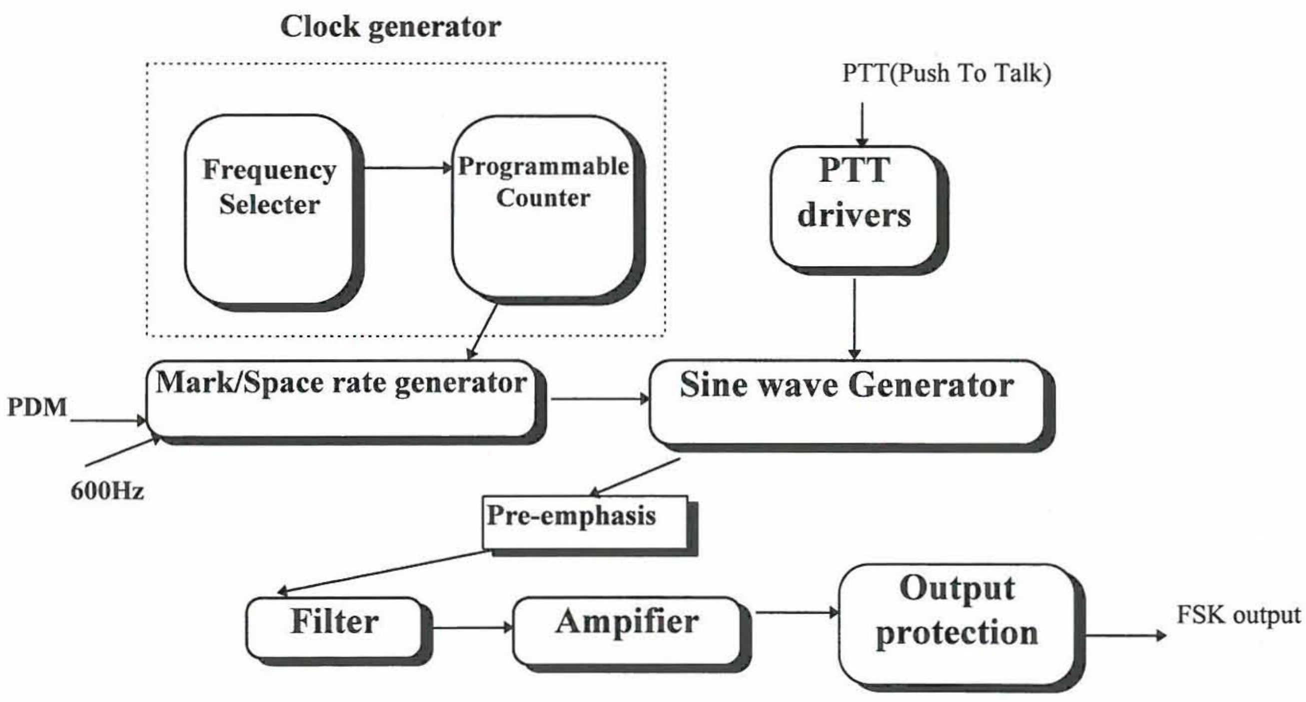


Fig. 4.2: Encoder block diagram.[12, p. 5].

The encoder encodes the PDM signal to FSK, and sends the signal (FSK output) to the radio interface.

The information to be transmitted is expressed by the MPU as a pulse duration modulated signal, under software control. The 600 Hz system clock defines the pulse duration by generating an interrupt signal. This signal causes the MPU to perform the required transitions in the signal at intervals of T, 2T and 4T, according to the data bit being transmitted.

The resultant pulse-duration-output (PDO) signal passes through the PIA to the mark/space rate generator that synchronizes the PDO signal with the 600 Hz clock and uses the resulting signal to modulate a pulse signal.

The output of the mark/space rate generator is a square wave with a frequency sixteen times the frequency of the corresponding FSK mark or space tone. The square wave is converted to a sine wave of the required mark/space frequencies by the sine wave generator, in which a resistor network sums the outputs of a shift register to form the sine wave.

A lowpass filter improves the wave shape of the sine wave from the sine wave generator, and the sine wave is then amplified by the required amount in the amplifier, where a potentiometer permits adjustment of the signal level. The output protection circuitry provides the final balanced FSK output and protects the output against transients appearing at the FSK output terminals.

The FSK output signal is present only when a TRANSMIT signal from the PIA operates the PTT drivers, indicating that transmission is desired. When transmission is not desired, the PTT drivers inhibit the sine wave generator. The drivers also contain output circuitry to drive the input of the RF transceiver. The output circuitry provides both a dry relay contact, and a voltage level via optocoupler isolation to satisfy the requirements of the communications equipment in use.

4.1.4 The CIU decoder [12, p. 5].

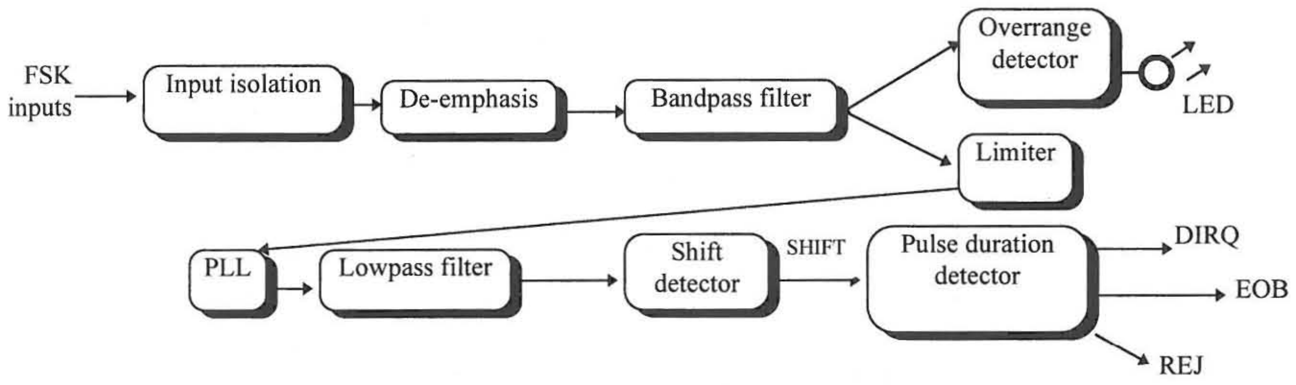


Fig 4.3: Decoder block diagram.

It is common knowledge that a decoder is the inverse of an encoder. It converts FSK mark/space tones to a data format acceptable to the MPU. The decoder decodes the FSK input signal to PDM. The input isolation circuit isolates the decoder from the communication channel, protects the decoder against input surges, and converts the balanced FSK input to an unbalanced output.

Practical tests on the CIU showed that after level adjustment the received signal passes the de-emphasis circuit and is filtered by the bandpass filter. The filtered signal enters the limiter that converts the sine wave to a square wave. An excessive signal level, which may cause saturation of the limiter, causes the overrange detector to light a LED mounted on the board, implying that an adjustment of the level is required. This was also tested and proved to function correctly by injecting a very high signal at the FSK inputs.

The square wave from the limiter enters the phase locked loop (PLL) circuit. This generates an internal clock, that follows the received FSK mark or space tones (when the PLL is locked), but has a phase difference that varies according to the tones.

The output of the PLL is a square wave with a dc level proportional to the received FSK tones. This signal is averaged by the lowpass filter circuit and then enters the shift detector that finally reconstructs the pulse duration signal.

The pulse duration detector measures the intervals between the SHIFT pulses in increments of 0,75T and accordingly generates the signals sent through the PIA to the MPU. The Decoder Interrupt Request (DIRQ) signal is generated in synchronization with the SHIFT pulses and interrupts the CIU program in intervals of 0,75T. The End-of-Bit (EOB) signal informs the MPU whether or not a SHIFT pulse occurred prior to the interrupt. The Reject (REJ) signal notifies the MPU whenever the duration of the received data signal is less than 0,75T.

Noise added to the signal during communication requires that the MPU apply the following criteria to the reconstructed data to determine when that data replicates the original data:

- A pulse duration greater than 0,75T but less than 1,5T is recognized as logic 0;

- A pulse duration greater than 1,5T but less than 3T is recognized as logic 1;
- A pulse duration greater than 3T is recognized as a frame synchronization (FS) pulse;
- A pulse duration less than 0,75T causes rejection of the entire code word. The code word is sent again for a pre-selected number of retries, until the acknowledge signal is received. If the acknowledge signal does not appear during the pre-selected number of retries, the signal is presumed to be corrupted, and rejected totally.

Figure 4.4 shows a diagram of the pulse duration pulses.

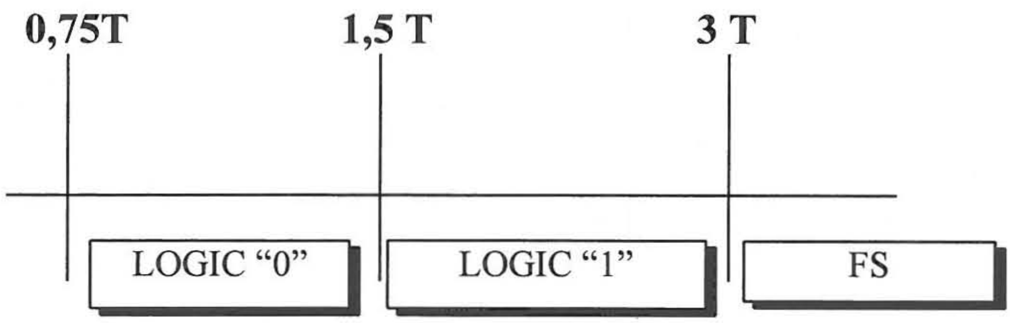


Fig. 4.4 : Pulse duration pulses.

Synchronization is re-established when the MPU senses the next FS pulse.

4.2 Auxiliary circuits of the CIU.

The auxiliary circuits consist of the system clocks, watchdog timer and the parameter switches.

4.2.1 CIU system clock [12, p. 6].

The system clock circuit generates various clock frequencies required in the CIU. All of them are derived from a basic clock pulse generated by the crystal-controlled oscillator in the MPU. The derived pulses determine the clock rates required for the encoder, the decoder and the watchdog timer, as well as the baud rate of CIU communication with the controller.

4.2.2 CIU watchdog timer and reset functions [12, p. 6].

The watchdog timer and reset circuit affects the restart of the CIU program by generating a RESET pulse for the MPU and the PIA. It monitors the transitions in a signal generated in the MPU by the CIU program and sent to the timer via the PIA. It causes a reset when a transition does not occur within a specified period. This is done because it assumes that the transition is corrupted, or stopped. The watchdog timer also monitors the ac power applied to the CIU and generates a RESET pulse when power is initially applied or restored after an interruption. The operation of the watchdog timer can be disabled from the normal "WATCH" position to the "OFF" state. Pressing the switch momentarily to the "RESTART" position, effects a manual restart.

4.2.3 CIU parameter entry.

Two arrays of parameter switches can be visualized in dual in-line packages, determine the initial setting of the CIU parameters that are read at each initialization of the CIU program. Messages from the controller may override the switch settings to change the parameters. A shift register allows the MPU to read the position of the switches via the PIA.

4.2.4 CIU audible alarm.

The audible alarm is normally operative but can be disabled. When visualizing the motherboard, one can see that it comprises a darlington driver and a sonic beeper, and is actuated by the PIA output to emit an alert tone

4.2.5 CIU channel monitor.

The function of the channel monitor is to monitor the channel for radio-busy signals, in order to prevent the transmission of data while the radio channel is occupied. This circuit informs the MPU when the communication channel is occupied. An external circuit (a squelch gate in the RF receiver or a corresponding circuit in a wire line unit) senses the presence of a carrier in the communication channel. It sends this information to the channel monitor circuit as a dry relay contact position or as a voltage level. The channel monitor circuit isolates this information from the CIU logic by means of an optocoupler and a floating power supply providing the dc voltage to operate the circuit.

A timer (PTT timer or push-to-talk) driver keys up the repeater for a pre-selected time period, before the data is sent out on the air. This ensures that the complete message is sent out after all the repeaters are linked up and keyed for the transmission of data.

4.3 Summary.

Located at the master station, the CIU forms an integral part in the functioning of the SCADA system.

The signals received from the MRTU decoders and encoders are converted into computer-operable language by the CIU. The CIU acts as a protocol converter between the LCU and the MRTU basic modules at the master station. The main component in the CIU is the MPS, a microprocessor that controls the transfer of all information to and from the peripheral devices.

The CIU performs important tasks, such as channel monitoring as well as encoding and decoding of the FSK signals received from the radio. These tasks are received by means of code words, and determine the protocol of the complete SCADA system.

Each CIU has its own unique system address, preventing unwanted alarms and controls to be performed at stations within reach of the same radio repeater. Therefore each domain requires a CIU, irrespective of the radio channels in that domain.

4.4 Personal involvement.

The author installed a Motorola CIU next to the LCU, to be used parallel to other channels exclusively for the purpose of the Pole-mounted breakers. This involved certain additional wiring, such as Tx, Rx, M & E communication wiring to the store and forward repeaters and microwave equipment which had to be completed and tested, in order to establish suitable communications.

During the tests, the author used a "Trend" data analyzer to test the RS-232 ports. From the CIU, a cable to the LCU was made up, and installed to the Longshine 24 channel cards on channel 16, after which it was tested and commissioned. Refer to section 5.4.2 and 5.4.3 for more detail.

An additional channel, channel 23, was configured on the LCU software, and wired to the change-over black-box for changing from Main to Backup mode. This cabling was wired to the RS-232 standard, with pin 4 and 5 joined, and Rx/Tx swopped at the CIU end.

After completion of the hardware, the author performed tests on the channel monitoring time-outs and interrogation cycles. The CIU levels were set correctly at -9dBm by means of local level meters and generators.

CHAPTER 5

MASTER STATION HARDWARE AND SOFTWARE CONFIGURATIONS.

Within the control centre, the pole-mounted telecontrol had to be implemented on the existing telecontrol infrastructure. This chapter details the existing infrastructure and highlights certain implementation considerations of the pole-mounted telecontrol. Much of the information contained in this chapter, is based on personal experience gained by the author in working with the system, and is therefore not referenced.

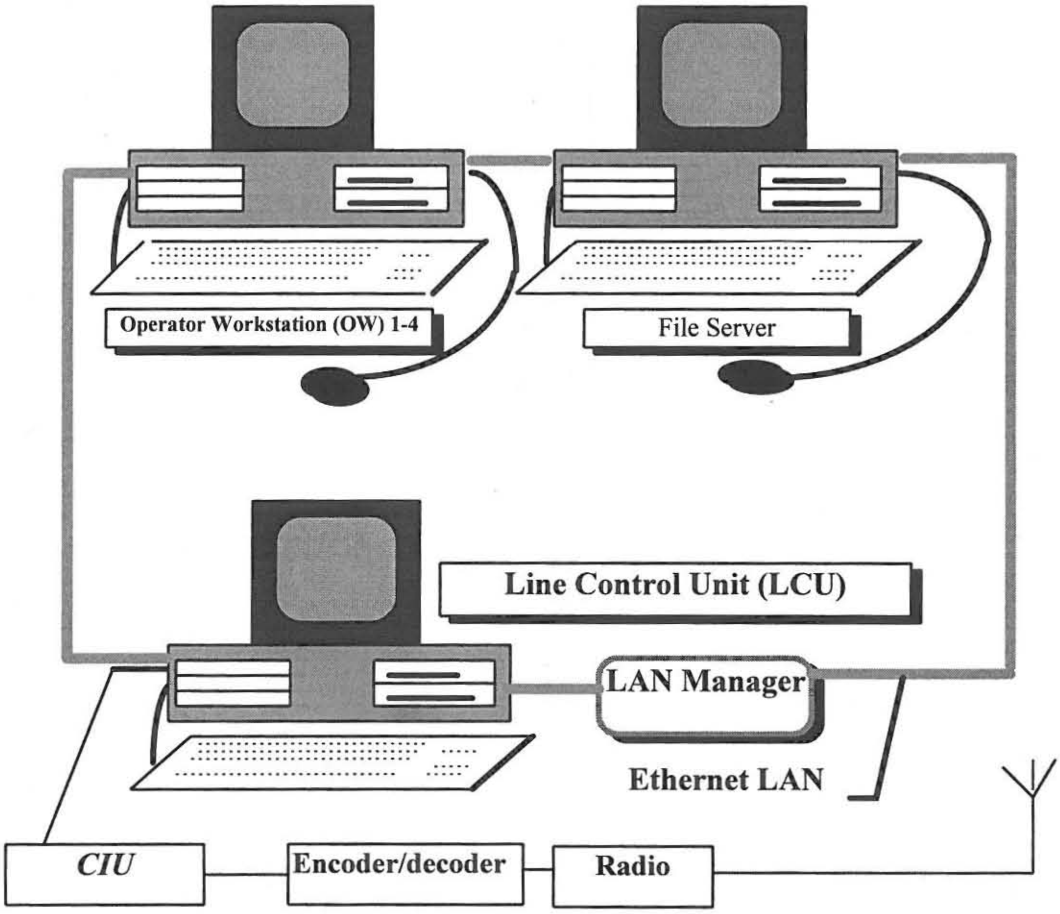


Fig. 5.1: Master station configuration.

5.1 Master station configuration.

The master station consists of PC-based operator workstations, a line control unit, and a file server, as shown in figure 5.1. Although all database information is stored on the file server, it can act as an operator workstation as well. Database changes can be done from the OWs as well, provided that access is allowed for the user to perform such database functions.

5.2 The operator workstation.

The remote MRTUs are monitored and controlled by the operator workstations. At the master station, the control staff monitor and control the MRTUs by making use of an operator workstation (OW). The OW communicates with the file server, via the local area network (LAN). The file server, in turn, communicates with the line control unit (LCU). The LCU acts as both a database (containing a portion of the information stored on the file server) and a protocol converter, which communicates with the MRTUs in the field in a language that enables the OWs to control the pole-mounted breaker units.

5.2.1 Operator workstation communications interface.

The International Organization for Standardization (ISO) created a subcommittee in 1977 to develop data communication standards. This resulted in the Open Systems Interconnection (OSI) reference model. [15, p. 2-1].

Because many types of computers exist today, which differ with respect to CPU, operating system, speed, etc., the differences between them make the communication problem between them non-trivial. Dividing difficult problems into sub-tasks allow them to be solved more easily, and the OSI model uses this “divide-and-conquer” strategy, where each layer executes specific functions. Fig 5.2 shows the OSI reference model. [7, p. 10].

The operator workstation communications interface utilizes three layers of the OSI 7 layer model, namely the network layer, datalink layer and the physical layer. [16, pp. 5-11].

The network layer moves information across a network from the LCU back to the operator workstations. The network layer controls a datalink layer for each OW connected to the LCU. The datalink layer in turn, controls the physical layers connected to the OWs. [16, p. 7].

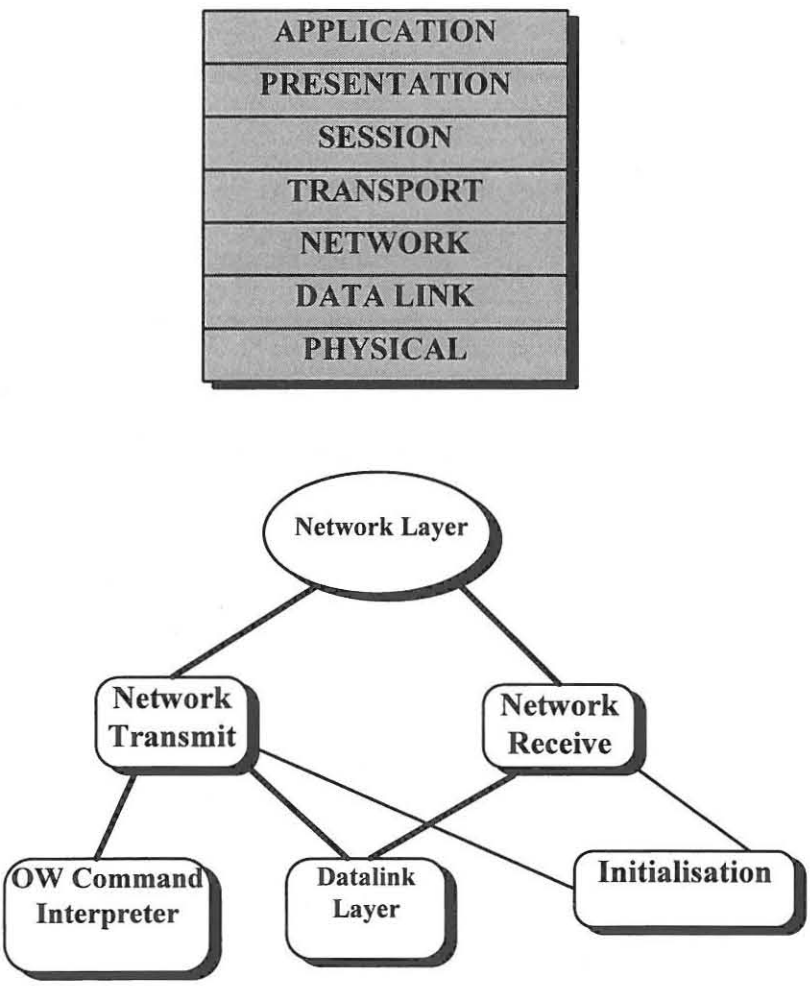


Fig. 5.2: OW communications interface network layer. [16, p. 7] and [7, p. 10].

5.2.2 Operator workstation (OW) channel configuration.

The OW configurations configured by the author required the following parameters to be configured.

- The operator identification address.
- Commands setup.
- OW / Server execution commands .

5.2.3 OW configuration for MRTU.

For each MRTU the following additional parameters were configured by the author for the completion of this project (see appendix C):

- Digital-to-Analogue I/O configuration.
- Control output parameters.
- General data (scan time).

5.2.4 Operator workstation alarm configuration.

The operator workstation, as part of the system that handles the interaction with operating staff, displays system information and status in a manner that is user-configured for optimal effectiveness. Alarms are prioritized and annunciated in an optimal manner that allows the operator effective control of his system. It also performs event-logging of both plant events, and operator actions. The operator workstation provides an operator with means to monitor and control the system plant. The operator workstation connects to the file server. The file server connects to the LCU and acts as the system central controller as previously described.

A number of OWs may be networked together using an Ethernet local area network.

The master station, based on the Sentinel SCADA package, has been developed for telecontrol systems with a large number of I/O points. It uses the OS/2 presentation manager and provides a consistent and modern interface to the operator. [16, p. 7].

5.2.5 OW graphic displays.

Graphic displays are pixel based. A Super-VGA monitor, operating with a resolution of 1024 x 768 pixels, is used. Graphic symbols and pictures may be created by the user and stored in a library. One or more display elements may be linked to one or more database points, in order to make these symbols dynamic. Analogue values and/or line symbols may also be displayed dynamically. The number of dynamic elements on a picture is limited only by the number of symbols practically to be fitted on the display.

Moveable windows provide flexibility with regard to positioning of the alarm banner, alarm list or event list. Each of these displays is in a window, and any portion of these windows may be positioned anywhere on the screen.

5.2.6 OW detailed display of MRTU.

Providing SCADA to pole-mounted breakers seems to be very uncommon, and therefore unique database configurations for this project were configured by the author, to enable the operator to "see" a complete imitation of the MRTU. The option to control and monitor pole-mounted breakers had not been implemented before in the Free State region, and a new and reliable database layout was developed to accommodate this need.

The layout of the MRTU display indicates as much detail as possible. The MRTU detailed display at the OW provides a symbolic and tabulated indication of the status of the MRTU. It also provides the time of last communication with the MRTU and additional control buttons, allowing the operator to call for an update poll of the MRTU, as shown in figure 5.3.

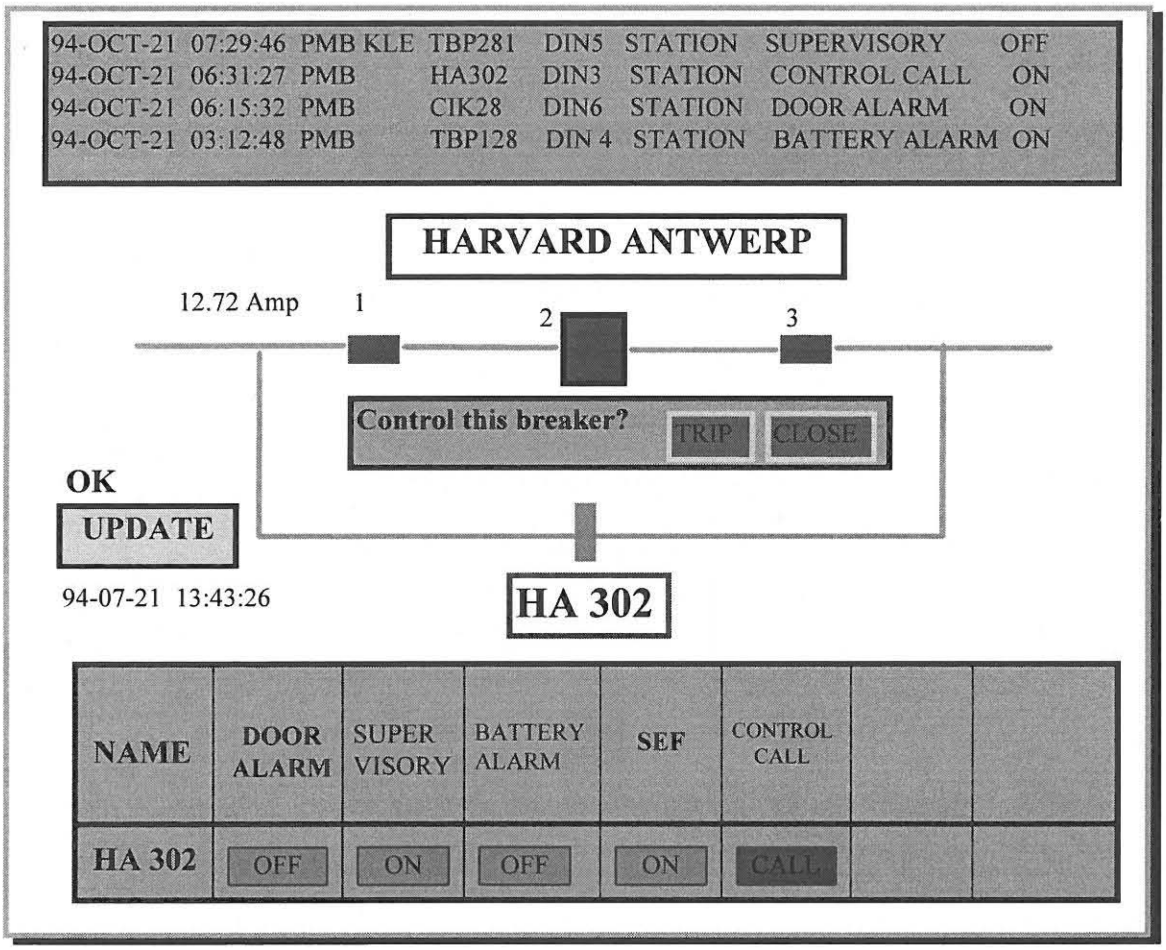


Fig 5.3: OW display of pole-mounted breaker condition created by the author for the purpose of this project.

Alarms are highlighted by flashing the indication. The following information would normally be displayed on the screen:

- Handdressed link indications (No. 1); Red = link closed, Green = link open.
- State of the breaker (No. 2 in figure 5.3); Red = breaker closed, Green = breaker open.
- Handdressed link indications (No. 3); Red = link closed, Green = link open.
- Door alarm; Red = ON, Green = OFF.
- Supervisory switch; Red = OFF, Green = ON.
- Mains or solar power failure (Battery alarm on fig 5.3); Red = solar failed, Green = solar OK.
- Sensitive earth fault (SEF); Red = OFF, Green = ON.
- Control call; Shows if the attention of the controller is required at the remote site.
- Analogue value of current consumption by users in ampere; Red = alarm state: Analogue out of limits, Green = within limits.

5.2.7 Communication status from MRTU to OW display.

For the purpose of this project, the programming done by the author is such that information concerning whether an MRTU is communicating or not is available to the system, showing OK if communication was good, and FAIL if communication is lost. This would normally be displayed adjacent to the relevant pole-mounted breaker update control block, with a user defined symbol UPDATE. A display indicating communication status of the MRTUs is also available (94-07-21 13:43:26 in figure 5.3), showing the MRTUs last communication time and date. The LCU will be responsible for maintaining this status in the system database. A MRTU will be deemed to be "in communication" if it responded to its last message from the master station.

5.2.8 OW alarms created for this project.

All status bits are configured to alarm when changing to the '1' state, the '0' state, or either change of state. Alternatively, alarms may be excluded for both changes of state. Non-alarm state changes are logged as events.

The operator can be alerted audibly as well as visually. Alarm annunciation is by means of the following:

- Alarm lists, at the top of the screen.
- Alarm state is shown on mimic display by means of different colours, which are user configurable.
- The device symbol will flash on the relevant detail mimic display, when in the unaccepted alarm state.
- The area overview screens can advise the operator of the occurrence of an alarm and/or unaccepted alarm by displaying a symbol in the relevant area.
- An audible alarm will sound.

The alarms can be accepted by the operators, and the flashing and audible alarms will disappear.

5.2.9 Database configuration extract.

The database configuration points configured for one of the MRTU outstations programmed by the author during the project is shown by the following database summary. This configuration is set up at the file server, and allows the MRTU to be controlled and monitored by the operators via the OW.

Database summary printed on TUE Jul. 12 13:57:58 1994

Station: MRTU Research project.......

Database updated by: FRIK----on Fri. Jun. 10 10:24:37 1994

Domains

01: System generated events

02: BLOEMFONTEIN

03: KLERKSDORP

04: BLOEMFONTEIN RETIC

05: WELKOM

06: WELKOM INTRAC (MINE STATIONS)

07: KLERKSDORP RETIC

08: PMB_BFN

*** PMB ***********************************

--- PMB.HA ----------------------

DIGITALS (DIN - Digital input)

DIN_1	HA302 22KV BREAKER
DIN_2	HA302 SUPERVISORY
DIN_3	HA302 OVER CURRENT

DIN_4	HA302 RURAL LINK
DIN_5	HA302 BATTERY ALARM
DIN_6	HA302 SENS EARTH FAULT

ANALOGS	(IIN - Integer input)
SPARE	ANALOGUE NO 1
SPARE	ANALOGUE NO 2
SPARE	ANALOGUE NO 3
SPARE	ANALOGUE NO 4
SPARE	ANALOGUE NO 5
ANA_6	HA302 22KV BREAKER

CONTROLS	(DOT2 - Pulsed 2 bit output)
CONT_1	HA302 22KV BREAKER

DEVICES	(DEV - Digital device)
DEV_1	HA302 22KV BREAKER

HANDDRESS	(HDOT - Hand dressed DOT)
HDOT_1	HA320 22 KV LINK
HDOT_2	HA54 22 KV LINK
HDOT_3	HA147 22 KV LINK
HDOT_4	HA212 22 KV LINK
HDOT_5	HA255/6 22 KV LINK

HDOT_6 HA260/1 22 KV LINK

HDOT_7 HA302 22 KV LINK

HDOT_8 HA311/17 22 KV LINK

HDOT_9 HA347347/77 22 KV LINK

DERIVED (DIN - Digital input)

RTU_FAIL RTU Fail alarm

RTU_COMMS RTU Comms

RTU_STATUS (DIN - Digital input)

RTU_CONFIG RTU Configuration

RTU_SYNC RTU Synchronise

SYNC (DOT - Digital output)

SYNC_RTU RTU Synchronise

TEST_RTU RTU Test

UPDATE RTU Comms

UTIM (DIN - Digital input)

RTU_TIME RTU Last comms

The digital inputs (indicating the state of the breaker), and the alarms occurring at the site are indicated by DIN_(X). The control outputs, controlling the breaker to trip or close are indicated by CONT_(X). The analogue readings are indicated by

ANA_(X). The non controlled and non monitored indications such as the line links are indicated by HDOT_(X). The DEV_X shows that the control is linked with the indication of the recloser. These database configured points are then linked to the specific symbol variable on the skeleton drawing, causing the variable to change colours or shapes, depending on the state of the alarm at that stage.

5.3 The line control unit (LCU).

The line control unit (LCU) is used to interface the operator workstations (OWs) to a network of modular remote terminal units (MRTUs) via a central interface unit (CIU), as described in chapter 4. In essence it is both a database and a protocol converter, converting the generally complex protocol used for communicating with MRTUs to a simple and efficient protocol for communicating with OWs.

The LCU incorporates a Windows-based man-machine interface (MMI) that allows the user access to the configuration parameters of the system, as well as the display of diagnostic information.

The heart of the LCU is a PC, which communicates with the operator workstation (OW) via the file server, as well as the MRTUs, via serial channels.

The LCU communicates information to the file server, which is then responsible for handling all aspects of data presentation to the OW. The OW is responsible for the handling of aspects of presentation to the operator, and all logging functions. Communications to the OW are directly from one of the file server's serial channels via screened cable. A D-type connector is used to connect the screened cable to the operator workstation (OW). RS 232 signalling is used. [6, pp. 1-5].

The LCU requires a minimum hardware configuration of a 286 AT machine with at least a 20 Mbyte hard disk, 640Kbytes real memory, 1 Mbyte extended memory, monochrome monitor and floppy disk. It also requires the DOS operating system version 3.3 or higher, and Microsoft Windows version 3.0 or higher. The hardware should allow Windows to run in standard mode. The amount of extended memory determines the maximum size of the system that can be controlled. [6, pp. 1-9].

5.3.1 LCU software.

The LCU acts as an interface between the OW and the CIU. The LCU also provides an interface to an operator. This is to allow the operator to configure the LCU, as well as monitor the status of the LCU. Configurations done by the author on the LCU are shown in Appendix C.

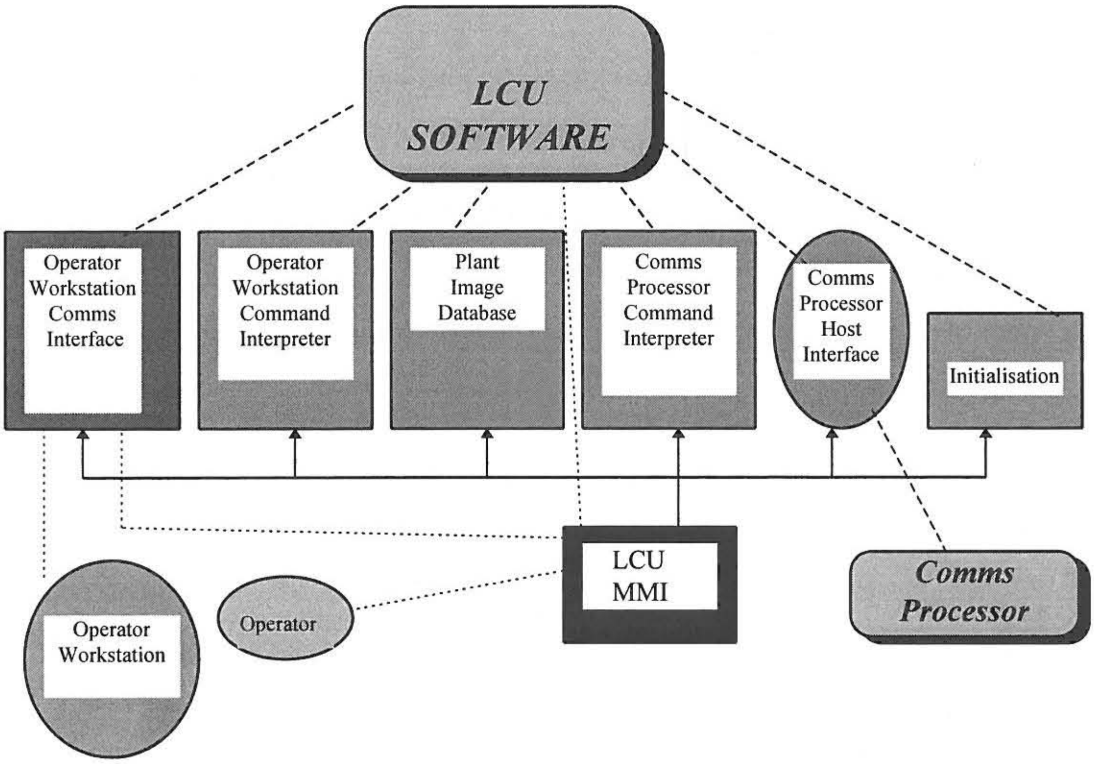


Fig. 5.4: Overview of the LCU software. [7, p. 8].

5.3.2 LCU channel control. [7, p. 9-21].

The LCU maintains the plant database; an image of the MRTUs. It communicates with the MRTUs, and pre-processes the data received from the MRTUs, for presentation to the OW in simplified form. With the OW/LCU protocol, data is provided to the OW in an event-driven form. Changes are queued, and it is not necessary for the OWs to scan the LCU database.

The LCU handles control requests from the OW and implements the required control procedures, again making the control status data available to the OWs in a simple format. Many system configuration items are selected at the LCU, namely those relating to the communicating network (PTT times, MRTU addresses) and the MRTUs.

The LCU is able to control up to 24 MRTU communication channels, and up to 4 master station channels. These channels all operate simultaneously, and may consist of any combination of supported protocols and hardware configurations.

5.3.3 LCU protocol to Intrac MRTU.

This protocol allows the LCU to communicate with the MRTUs via the CIU. The central interface unit acts as a front end for the LCU to the radio network, monitoring and controlling the MRTUs. The protocol for this channel allows full-duplex communications between the LCU and the CIU. Any message initiated by either device must be acknowledged by the receiving device before another message may

be initiated. Therefore communications from the CIU to the LCU consist of a CIU message and then an acknowledgment from the LCU and vice-versa.

The protocol incorporates "link-alive" checking that periodically polls the central interface unit, to ensure that the communications link between the LCU and CIU is still operating. [6, p. 18].

Whenever the communications link between the LCU and the CIU is initialized, the LCU downloads the configuration parameters to the CIU. This configuration consists of information informing the CIU of its operating parameters.

5.3.4 LCU scanning of the MRTU.

For practical reasons the MRTUs were chosen to be report-by-exception MRTUs, and should be scanned at regular intervals to ensure database synchronism. This takes place in two separate phases.

❶ On power-up or reset of the LCU, an initial scan of each MRTU on each channel is performed. This occurs at a configurable rate which is the same for all MRTUs. The object of the initial scan is to obtain the plant status as quickly as possible. All data received from the MRTUs during this scan is passed into the master station, whether or not the data has changed from the last known to the LCU or not. The data for each MRTU is flagged as being valid if the MRTU responds to the initial scan.

❷ Once the initial scan of the plant MRTUs has been completed, the LCU proceeds with the normal background scanning of the MRTUs. The rate of this scanning is configurable per MRTU. As in the initial scan, the data received from the MRTU is passed on to the master station whether or not it has changed.

Programming done by the author caused both the initial scan and background scan to send the direct interrogate command (DI) to the MRTU concerned. The direct interrogate command causes the MRTU to return with its complete plant status. Change-of-state messages from the plant MRTUs were passed on to the master station only when the data differed from that which were already present in the LCU database.

5.3.5 MRTU data at LCU.

The LCU can also display a representation of a specific MRTU in its database. The display is updated dynamically as data is received from the plant MRTU being shown. The data is displayed as raw data, i.e. no processing or scaling is applied to the data, except for analogue input and output values that are scaled to mA values. Digital values are displayed in groups of eight bytes, reading left to right with the most significant bit first, as shown in figure 5.5. All values are tabulated in a left to right, top-to-bottom order on the display pages. From these displays, it is possible to correlate the data from the plant MRTUs with the data being stored in the LCU database, and finally being stored and displayed in the master station.

USER	STATUS	CONFIG	STATISTICS	CONTROL	EVENT LOG	DEBUG	BACKUP	RTU CHANNEL

01000000	01001000	00000000	01000000	00000000	00100000	00010000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00100100	00000000	00000000	00000000	00001000	00000000	00000000	00010000
00000000	00000000	00010000	00010000	00000000	00000000	00000000	00000000
01000100	00000000	00000000	00000000	00000000	00001000	00000000	00000000
00010000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
01000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00010000	00010000	00000000	00000000	00000000	00000000	00000000	00010000

31/07/94 15:48:30 COMMUNICATIONS FAIL TO MRTU 60 (TWEEELING MRTU)
31/07/94 15:49:22 COMMUNICATIONS RESTORED TO MRTU 60 (TWEELING MRTU)
31/07/94 15:51:22 COMMUNICATIONS FAIL TO MRTU 03 (BERGPLAAS MRTU)

Fig. 5.5. Raw data received from the MRTU,

5.3.6 LCU/OW communications channel control.

The protocol for this channel allows full-duplex communications between the LCU and the OW via the LAN. Any message initiated by either device must be acknowledged by the receiving device before another message may be initiated.

Communications from the OW to the LCU consist of an OW message and then an acknowledgement by the LCU. If the message is a write to database (LCU), which will influence the MRTU, then the LCU will also respond at a later time with the result of the write operation. These write results' messages may show one of four different results:

- The write operation was performed successfully.
- The write operation caused no operation since the data to be written into the LCU database was the same as that already present.
- The write operation was successful in changing the LCU database, but the plant MRTU for which the data was intended report an error for that data change.
- The write operation was successful in changing the LCU database, but the plant MRTU for which the data was intended did not respond to the command message (MRTU comms failed).

Whenever the communications link between the LCU and the OW is initialized, the LCU first sends an "alive poll" message with its real time to the OW. In turn the OW will perform a full database upload sequence, reading the data from the LCU database for each tag configured in the OW database.

"Link alive" checking consists of the LCU periodically querying the OW with a link-check message. The OW must always acknowledge this message for the link to be considered alive. Every twenty fifth link-check also contains the LCUs real time clock setting that the OW will use to update its own real-time clock.

The OW also performs a background scan of the LCU when it is not otherwise engaged to assure database synchronism.

5.3.7 LCU event logging.

The LCU logs events and alarms as they occur to the event and alarm list, recent events, event history log disk file and the event printer.

These events are time tagged at the time of occurrence. Alarms and events typically concern communication errors and failures, as well as user manipulation of the database. The event log files may be used to keep an archived history of all events and alarms that have occurred at the LCU. An example of such a recorded event is shown in figure 5.6.

5.3.8 LCU diagnostic functions.

During operation of the LCU, all messages being transmitted and received on each communications channel may be displayed against the channel number concerned. Each new message overwriting the previous displayed message, or a scrolling message can be displayed.

The messages are displayed in a format specific to the protocol being used on each channel. All messages are displayed with the protocol being used, the RTU concerned, the command or function of the message, and then any other data of the message in a form peculiar to the specific protocol.

06/09/94	07:30:41	Transaction timed-out for MRTU 5708 (VAALRF 11)
06/09/94	10:27:36	Communications failed to MRTU 37 (PMB MRTU 37)
06/09/94	15:47:22	Communications restored to MRTU 37 (PMB MRTU 37)

Fig. 5.6: Communications channel messages.

From these displays, it is possible to deduce the successful, or otherwise, operation of each communication channel, as well as check that data is passing backwards and forwards along the channel as expected.

5.3.9 <u>Communication statistics.</u>

The LCU also compiles statistics for each communication channel. These statistics include the number of messages transmitted and received, the number of retries performed, the number of message time-outs, and the number of messages received in error. The communications statistics display page is dynamically updated while the LCU is running.

5.3.10 <u>LCU man-machine interface (MMI).</u>

The user interface of the LCU is that of a Windows application. The standard Windows application operating techniques are used throughout the user interface. The LCU MMI may be driven from the keyboard as well as a mouse.

The LCU window is divided into six main areas. Each of these areas is a separate window that has it own individual functions. In addition to these fixed windows, various entry forms and dialogue boxes may be displayed over these windows while operating the LCU.

5.3.11 LCU main menu bar.

The main menu bar contains all the functions that are accessible to the user. The functions shown in the main menu bar are known as the top-level items. Most of these top-level items allow access to lower levels of additional pop-up menus. The top-level items gather together the functions of the LCU into logical groups.

5.3.12 LCU date and time bar.

This displays the current system date and time. It is updated every second.

5.3.13 LCU main window area.

The main window area is used to display the data contained in the LCU. The following display pages are available:

- communications status page.
- communications statistics page.
- MRTU status page.
- event log page.

5.3.14 Alarm window.

The alarm window for the MRTUs configured by the author displays the three most-recent events or alarms that have occurred at the LCU. Alarms do not need to be acknowledged by an operator. The alarm window scrolls up when a new alarm or event is received.

06/09/94	07:30:41	Transaction timed-out for MRTU 143 (MASERU)
06/09/94	10:27:36	Communications failed to MRTU 227 (PMB MRTU 47)
06/09/94	15:47:22	Communications restored to MRTU 227 (PMB MRTU)

Fig. 5.7: LCU alarm window.

5.4 LCU/MRTU system configuration.

The configuration of the LCU, MRTU and master station is divided into a number of clearly defined stages. These stages are reflected in the structure and grouping of the configuration menu items.

The current configuration of the LCU can be changed at any time while the LCU is running. If the changes are accepted, they will be stored immediately in the current configuration.

The LCU program allows more than one configuration to be stored on the hard disk. Each stored configuration may be different, and may be loaded at any time to replace the current configuration.

5.4.1 New LCU configuration.

When a new configuration is executed, it clears the current LCU configuration, and replaces it with a default configuration that contains no MRTU communication channels, no master station channels, and no MRTUs in the plant image database. A set of defaults is used for the other configuration parameters.

Once the new configuration has been created, it starts running. Additions and changes may now be made by using the other functions in the configurations' menus.

5.4.2 Hardware configuration.

The hardware configuration for the MRTU and master station's communication channel is set up during the definition of these channels. The same form of entry is used for all hardware configurations, some of the fields being required, whilst others may be ignored for specific configurations.

The following channel definitions are relevant for the hardware configuration: [6, pp. 9-10].

- Internal PC [RS-232] communications ports (COMx).
- Longshine LCS-8682 Communications Card Configuration
- Net Bios LAN Connection Configuration.
- Dynamic Link Library (DLL) configuration.
- Dynamic Data Exchange (DDE) configuration of Windows.

5.4.3 CIU interface configuration.

This protocol selects the radio network for communication to Intrac MRTUs via the CIU. The configuration parameters used by the author are as follows:

- Channel address.
- Retry time period.
- Maximum number of retries.
- Start-up scan time.
- Background scan delay.
- System configuration.
- System address.

- PTT delay.
- Number of words for auto interrogation.
- Auto interrogation on and off time.
- Number of auto interrogation attempts.
- Inter transmit time.
- Computer busy time.

5.5 Conclusion.

During this project, the configuration on the operator's display was configured to indicate the actual condition of the remote unit. The control functions and analogue readings were also configured to be displayed on the same operator screen. This is displayed on the OW's super VGA monitor. The OW communication task uses data communications standards, such as the OSI 7 layer model.

The future trend goes towards knowledge-based systems that offer the operator reliable estimation of system state, aid in fast analysis and support for rapid and automatic power restoration after a serious supply breakdown. Therefore alarm limits were applied to individual alarms. Otherwise the operator would not be in a position to handle all the information he receives in emergency situations.

The master station consists of PC based operator workstations, file servers and a line control unit. The LCU incorporates a Window based MMI, working on a LAN, interfacing the MRTU at the remote site to the actual operator display.

After completion of this project, the database configuration performed on the LCU and OWs operated successfully, showing all relevant indications, and allows the operator to quickly access the relevant display. The remote unit's layout at the OW seems to be comprehensible, and the information showed on the screen and alarm page is sufficient for the task.

Therefore the configuration of the MRTU remote unit is successful, and enables the control staff to have a reliable view of the remote station, and its status.

5.6 Personal involvement.

This chapter includes a brief description of database and software configuration changes performed at the master station. This includes all OW alarm configurations and OW channel configurations that were performed. Each OW's unique channel configuration to the Main Server was programmed in order to supply the operator's identification address, commands setup and the execution commands. A brief example is shown in Appendix C, paragraphs 9.1 and 9.2.

The OW detailed display was built at the Main Server, using the Sentinel OS/2 software. Skeleton displays were designed and configured. Database configurations were performed, and proved successful.

The layout, database and alarm configurations proved successful and were used for commissioning of all the other pole-mounted breakers that have since been installed in the region. The standard, as configured by the author, was still used as a norm for all pole-mounted breakers in the Free State, Northern Cape and Western Transvaal regions at the time that this dissertation was written.

Section 5.2.9 shows an extract of the database configuration as configured by the author for a specific pole-mounted breaker. This configuration was repeated for all the other units that were commissioned.

Section 5.3. shows the result of LCU software programming, and Fig. 5.5, 5.6 and 5.7 indicated the success of the LCU configuration changes done by the author .

CHAPTER 6

REMOTE ACCESSORIES AND MODIFICATIONS

A major portion of the work done in the execution of the project related to the adaptation of existing pole-mounted circuit breakers to telecontrol. When this project was initiated (1991), suitable interfaces were not yet commercially available in SA., and the author had to overcome a number of technical obstacles in implementing the total system, as will became apparent from this chapter.

6.1 The recloser (pole-mounted circuit breaker).

To understand the implementation of SCADA modifications on the reclosers, the complete operation of the recloser must be considered. Operation and modifications of only type KFE reclosers are discussed in detail in this chapter. As the functioning of other types of reclosers is very similar, their operation is discussed very briefly. However, the modifications on each type differ to a great extent, and these are discussed in detail.

A recloser can be compared with a circuit breaker, which interrupts electric power under fault conditions. In order to restore power, the fault must first be cleared by tripping the circuit breaker. The recloser automatically attempts to restore power by closing after a preset time period, and for a limited number of attempts. Interruption of power is achieved by means of electrical circuits which sense the fault conditions, and operate at pre-selected fault currents. When the recloser finally trips and lockout occurs, the recloser must be reset by an operator, or restored via the supervisory system.

Since 1960, reclosers have been refined and improved to their present, basically maintenance free state. Reclosers are able to operate (mechanically or electrically) only during faulty line conditions. When operated and locked out, the recloser has to be manually reset to the original state, in order to restore the electricity supply. The electronic operation of some of the reclosers has added more simplicity, accuracy, and flexibility to the power system. It must be clearly understood that reclosers only operate under fault conditions, and are not able to restore power automatically after a permanent fault is cleared. Therefore any recloser without SCADA facilities cannot be used to isolate or restore electricity supply by itself. Most reclosers operating with electronics do not provide supervisory control. The electronics though, can contribute to a great extent to operation of the recloser by means of the supervisory system, with the aid of external electrical circuitry and actuators.

Reclosers, or pole-mounted breakers, as they are commonly known, combine the self-contained durability and simplicity of hydraulic control, with the accuracy and flexibility of solid state electronics.

According to McGraw Edison Power Systems [10, pp. 2-10] three-phase, electronically controlled reclosers are completely self-contained, with no external power source or battery. Power is obtained from the primary sources by means of bushing current transformers. McGraw reclosers have six 1000/1 ratio current transformers mounted on the bushings under the head, which provide both phase and current sensing. The CTs are connected to the electrically controlled cabinet through the control cable. A minimum of 5 ampere primary current flow is required to power the electronics.

Reclosers are designed to be mounted on a pole structure as shown in figure 6.1, with ground tripping as low as 5 ampere in both inverse and definite time curves. Long life, maintenance-free sealed vacuum interrupters provide quiet current interruption, without oil contamination and contact wear associated with other interrupting media. They make use of electronically controlled circuitry, for instantaneous phase- and ground-tripping, and fault indication.

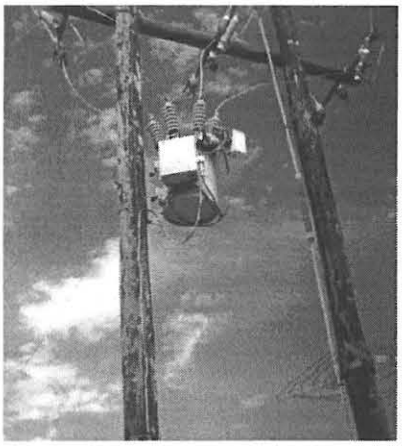


Fig. 6.1: A type KFE recloser, mounted on a pole structure, showing the external cabinet mounted on the side of the recloser.

Oil is used for electrical insulation in the operation-counting mechanism, and in establishing timing of reclosing operations. Since the McGraw recloser is a vacuum recloser, no oil is involved in the interruption of the arc.

According to McGraw Edison Power Systems [10, p. 9], the electro-mechanical design provides self-contained operation by movement of a solenoid plunger that loads springs, closes contacts and releases spring-loaded mechanisms. The complete internal mechanism, suspended from the head casting, can be removed from the tank as a unit, as can be seen in figure 6.2.

6.1.1 Electrical operation.

According to McGraw Edison Power Systems [10, p. 3], fault currents are sensed by six bushing-current transformers mounted under the head of the recloser. Whenever any phase or ground current exceeds the minimum trip level, and remains above that level for a selected timing period, the low-energy tripper is energized by the energy-storage capacitor. This releases the charged opening springs. Opening of the recloser contacts releases the closing-solenoid plunger and allows it to travel upward to close the phase-to-phase connection to the closing solenoid. With the closing solenoid re-energised, a closing operation is accomplished.

6.1.2 Manual operation.

Connection of six recloser bushing terminals, as shown in figure 6.2, to the three-phase system prepares the recloser for operation. Raising the yellow manual operating handle, connects the closing solenoid across two phases. This causes the closing solenoid plunger to be drawn into the solenoid. Through the recloser mechanism, this downward movement of the plunger closes the vacuum contacts, loads the contact pressure springs and the opening spring, and opens the phase-to-phase connection to the solenoid. The plunger is latched in the downward position after the vacuum interrupter contacts are closed.

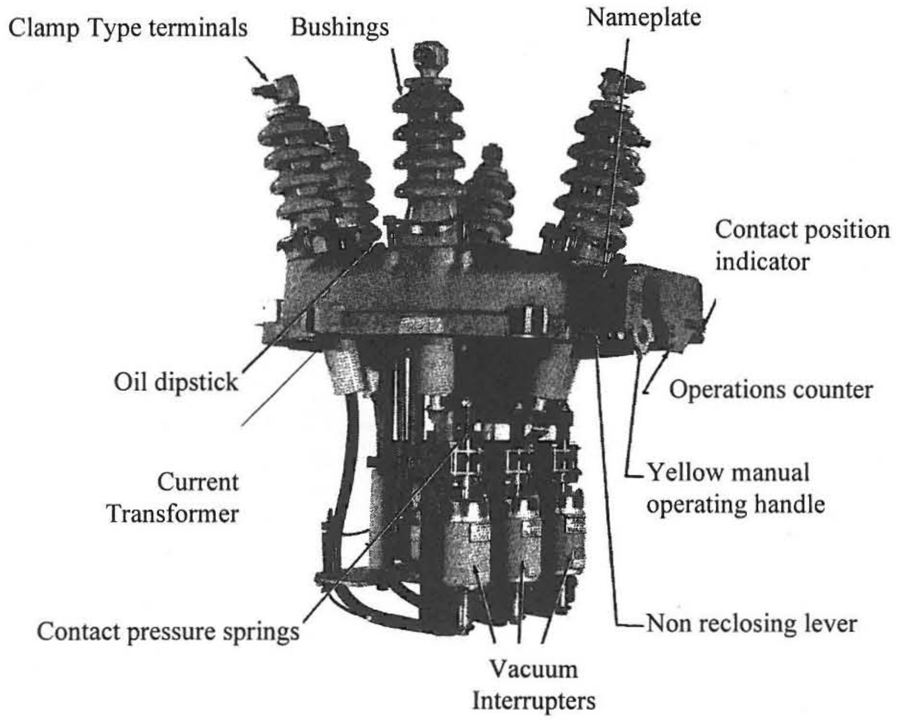
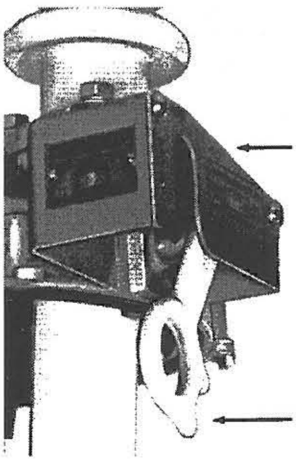


Fig. 6.2: An untanked recloser.[10, p. 2].

According to McGraw Edison Power Systems [10, p. 6], energy that operates the reclose mechanism to close the vacuum interrupter contacts, compresses the contact pressure springs, and charges the opening spring, is obtained from the system through a high voltage closing solenoid. This solenoid is connected phase-to-phase on the recloser's source side through a high voltage contactor.

The closing operation is best understood by considering the recloser to be connected to the line, but locked out (manual operating handle downwards). To close from lockout, the manual operating handle is raised to the closed position. An illustration of the yellow operating handle is shown in figure 6.3. This allows the closing solenoid contactor to close the phase-to-phase connection, thereby energizing the closing solenoid and imparting a downward acceleration to the solenoid plunger, which, according to McGraw Edison Power Systems [10, p. 6], causes the recloser operating mechanism to act as follows:

- ☞ The contact operating rods move downward to close vacuum interrupter contacts and compress contact-pressure springs.
- ☞ The closing solenoid contactor opens.
- ☞ The plunger is latched downward, charging the plunger-return springs.



Breaker close

Operating handle to upper side.

Breaker tripped and locked-out.

Operating handle downwards

Fig. 6.3: Operating handle of recloser.

While the recloser contacts are closed, the solenoid plunger remains latched in its downward position. Release of the recloser-opening spring releases the plunger latch, and allows the plunger to be drawn upward under action of the plunger-return springs. As the plunger reaches the top of its stroke, the closing solenoid contactor again closes, momentarily energizing the closing solenoid, and drawing the plunger back down, to repeat the closing operation.

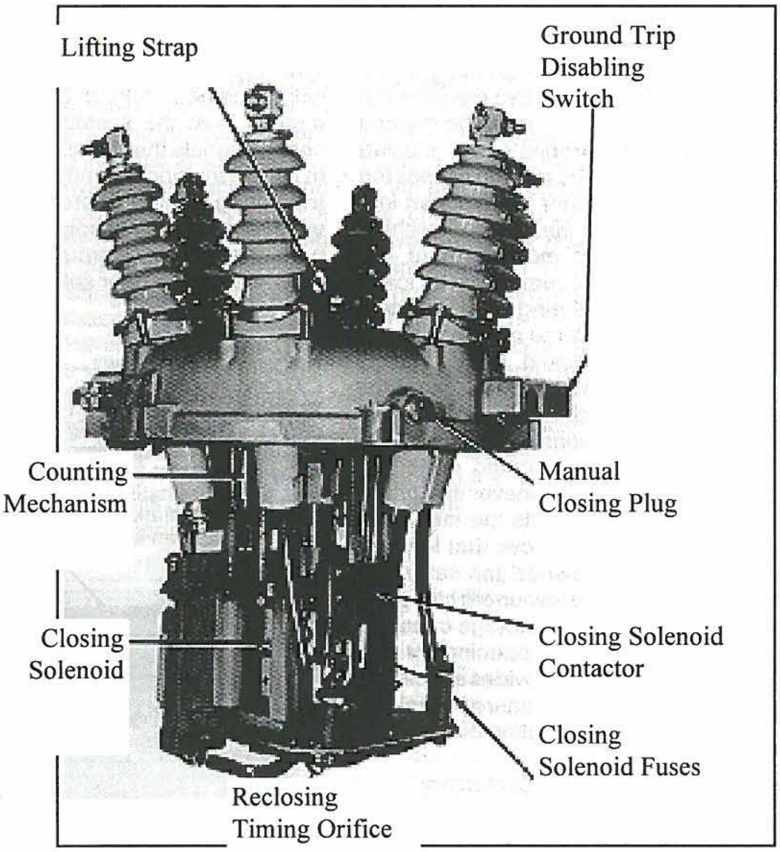


Fig. 6.4: Inside view of recloser mechanism, showing the closing solenoid [10, p. 3].

During the closing operation, an electro-magnetic charging coil instantaneously charges the trip capacitor (figure 6.5), ensuring that the recloser is armed and ready for an immediate trip operation if necessary.

This closing operation only acts in order to restore lost supply when temporary line faults occur, and cannot be used to restore power when the recloser is in the lockout position.

When the recloser is closed, the tripper-armature plunger is held in by the magnetic force of the permanent magnet. In this position, the armature spring is compressed and energized, ready to withdraw the armature when magnetically released.

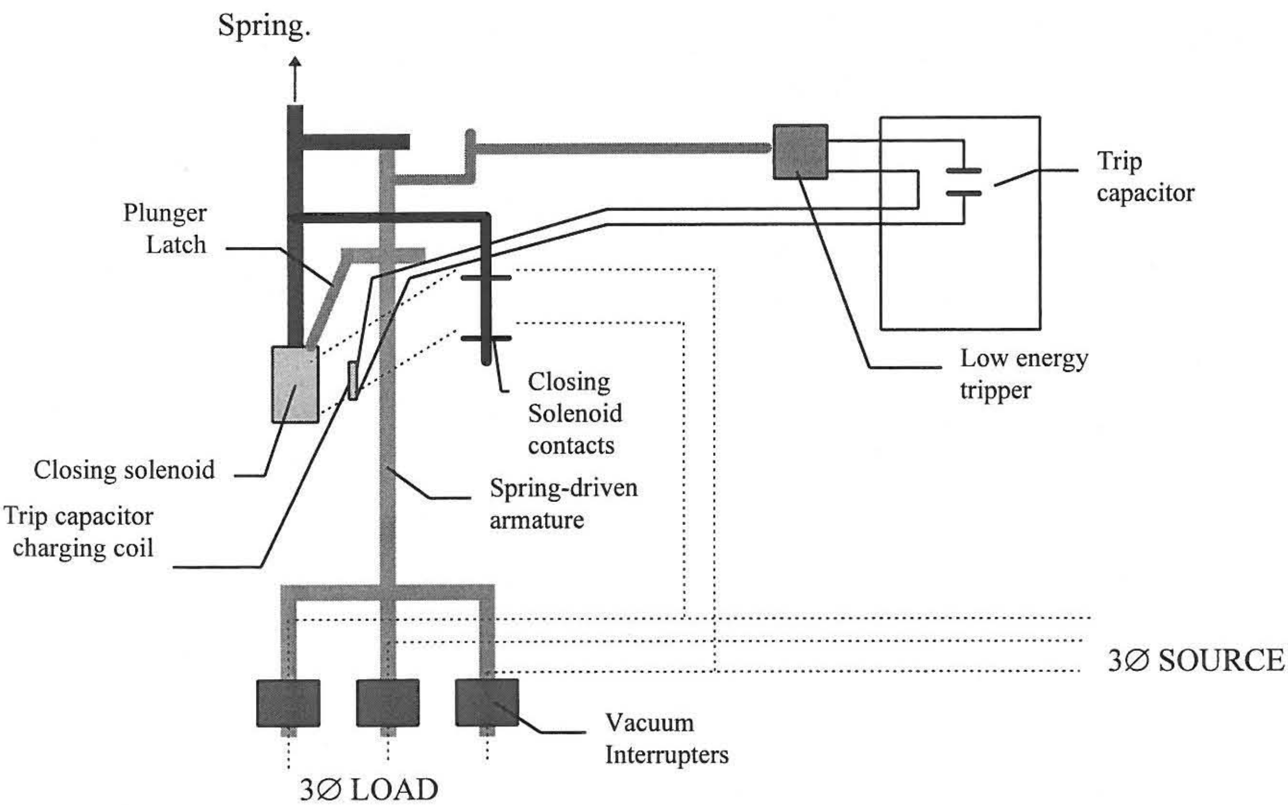


Fig. 6.5: Simplified diagram of the major electrical and mechanical components of the recloser.

It is commonly known that a lockout condition occurs mostly during stormy weather conditions, thus endangering human life while manually operating the recloser at such times. SCADA equipment eliminates this danger, and also saves time and travelling to and from the reclosers, looking for the faulted section of power line.

With SCADA implemented on reclosers, the control centre immediately knows where the faulted line sections are. The operater can immediately restore electricity supply when obstructions on the power line are cleared, even if the power lines are situated at an isolated or inaccessible site.

6.1.3 <u>Trip operation.</u> [10, p. 6].

During a trip operation, the stored energy in the trip capacitors energises the solenoid coil in the low-energy tripper. This creates a counter-magnetic field that momentarily neutralises the field of the permanent magnet inside the tripper, thus allowing the spring-driven armature to instantaneously operate the trip lever, which opens the recloser contacts. As the recloser contacts open, the pre-charged reset spring is released, and returns the solenoid plunger to the de-energized position. The low-energy trip assembly is then re-tensioned, and able to perform another trip operation. If a permanent line fault occurs, the recloser trips again after reclosure, and lockout occurs. The electricity supply to the customers is interrupted until human operation manually closes the recloser with the operating handle, or via supervisory.

The modifications carried out on these units are described in section 6.3.

6.2 Electronically-controlled reclosers.

For the type KFE recloser, the electronic accessories are located in an external cabinet, connected to the recloser with a cable (figure 6.1). The separate control cabinet is intended to be mounted against the recloser tank, although it can be mounted against the pole or other mounting structure at a distance limited by the cable length. This type of recloser was not designed for telecontrol functions, but during this research it was proved that telecontrol functions can be implemented successfully.

In the type ME Reclosers, the electronic circuitry contains microprocessor-based control functions. This was investigated as a means of easing the process of converting the controlling and monitoring of the breaker via supervisory.

The type ME electronic reclosers used in the Free State distributor region comprise of the ME 280-75, the types 4C ME S280-77-1 and the 3A S280-75-1. The types ME 280-75 and the 3A type electronic recloser's automatic control functions are performed by solid-state electronics. A sealed nickel-cadmium battery supplies the power to initiate the recloser's trip and close operations. Communication between the control and the recloser is accomplished via shielded conductor, isolated cable and waterproof connectors. All the recloser settings can be carried out from the front panel, which include the following (as can be seen on the face plate):

- Minimum trip current ratings.
- Ground and phase trip timings.
- Operating sequence.
- Reclosing interval timing.
- Reset time.
- Manually close and trip.

The type 4C S280-77-1 contains a microprocessor based recloser control unit, with its own power source. All the settings and control functions can be done from the front panel, including the manual close and trip functions.

The 4C type is equipped with an event recorder to provide detailed keyboard-accessible fault historical data, for system analysis.

During the course of this research project, driver units, actuators, and an MRTU were developed to cater for all reclosers in use in the O.F.S. to enable them to be controlled via supervisory. This enabled the Eskom Free State distributor to control all existing pole-mounted reclosers in the region, as well as some sectionalisers, if required.

6.3 Supervisory control modification.

6.3.1 Remote trip (KFE Type).

In order to supply SCADA to reclosers, a few options were tested while modifying the reclosers. When remote trip is initiated on a modified type KFE recloser, a signal must be received by the MRTU from the master station. This must enable a remote lockout accessory to trip the recloser, and lock out its mechanism. The recloser's manual operating handle must drop to its lockout position, providing a visual indication that the recloser is locked out. Three methods were tried:

❶ By applying a constant voltage to the current transformer and grounding the tripper contact point to the control panel ground, the recloser trips and locks out instantaneously without intentional time delay. With this small modification, the normal working of the recloser is not influenced, because the signal controlling the trip command only appears for a pre-selected time period when controlled by the operator via supervisory. Although this method proved to be successful, the close function seemed to be a problem, and the electrical circuitry could not be modified with low-voltage applications to close the recloser. Further tests were performed, in the search of more practicable ways to control the recloser, as this option only catered for half of the requirements.

❷ Two 12 volt solenoids, one for pulling the yellow operating handle to trip the recloser, and the other solenoid to close the recloser were installed. This option seemed more successful, but the disadvantage was that the solenoid's moveable distance was not sufficient and could not reach the whole stroke, therefore a lever pivot was used in collaboration with the two solenoids to solve this problem. These moveable parts caused the actuator to stick after a number of operations.

Although this option seemd workable, the possibility that the control operation could fail if not maintained regularly, discouraged the implementation thereof. As the aim was to reduce maintenance on the SCADA system to a minimum, this option was not recommended for controlling pole-mounted breakers.

❸ A 12 volt dc motor, mounted on top of the lockout handle case was installed to pull down the lever in order to trip the recloser. The dc motor received its power from an electronic circuit. This circuit was installed next to the MRTU, which provides the necessary signals to put the motor in forward or reverse motion, depending on the signal received from the MRTU. The motor used is absolutely maintenance free and moisture resistant. This option was the ideal solution, and operated without any failures. As a water resistant motor was used, it operated succesfully in adverse weather conditions.

An electronic circuit was developed to control the motor in order that the operable parts of the motor could be seperated from the manual or electrical operating parts of the recloser. The motor and electronic circuit were built and installed on the recloser, and operated as follows:

On the trip command, the motor arm moves from a neutral position, anti-clockwise, to push down the yellow operating handle of the recloser. This causes the recloser to trip and lock out, as shown in figures 6.6 and 6.7.

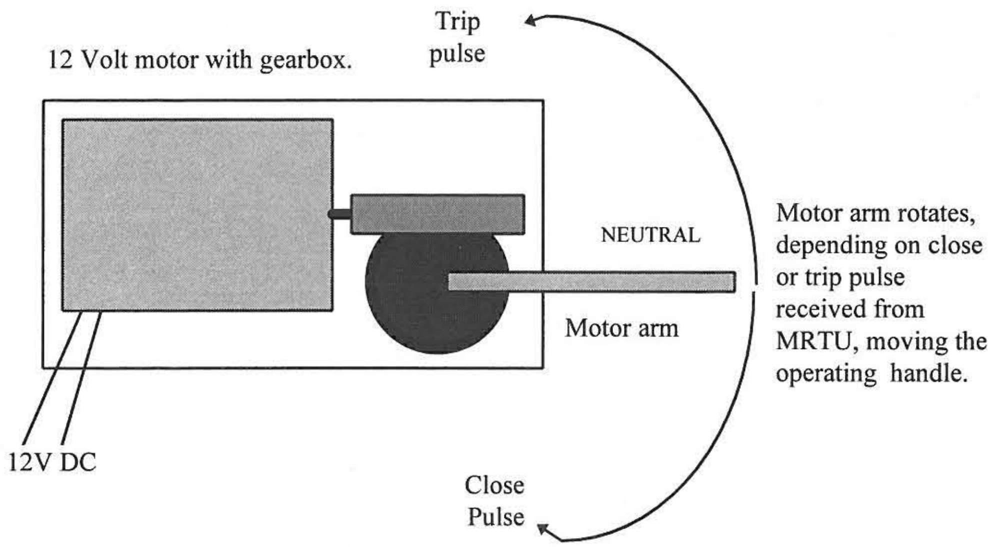


Fig. 6.6: Illustration of the motor assembly, developed as an actuator to control the recloser.

After completion of the command, the arm moves back to a neutral position, and stays there until further commands are received from the MRTU. The electronic circuit designed for the control functions consists of relays, micro-sensor switches and 555 timers, as shown in figure 6.8.

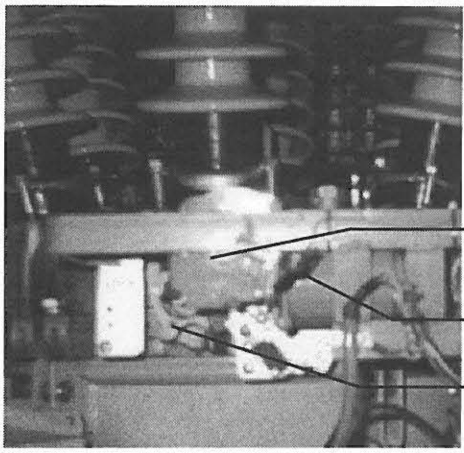


Fig. 6.7: Picture of motor-assembly.

When the master station sends a trip pulse to the MRTU, the trip control relay of the MRTU is activated. This relay sends a 12 Vdc signal to the electronic circuit which was developed to control the motor assembly. Relay 2 energises, and supplies a 12 Vdc signal to the motor. The motor operates anti-clockwise, pushing down the yellow operating handle, and causing the recloser to trip and lockout. The normally-closed contact of C2 is then opened by the motor arm, preventing the motor from labouring, in case the trip signal received from the MRTU is set too long. The motor is de-energised until the trip signal disappears. When the trip signal disappears, relay 2 is de-energised, and the forward timer starts. This timer sends a 12V inverse polarity signal to the motor, via relay 4, moving the arm clockwise to the neutral position. When the timer interval expires, the operating arm of the breaker remains stationary. The operating handle of the recloser can now be operated manually or electrically if necessary. The arm of the motor does not interfere with the regular working of the breaker, because it is moved away, to a neutral position.

When an unwanted control signal is sent from the control centre, a safety contact is used. This contact prevents the motor arm from moving to an unwanted position. This is done by C3. When the breaker is in the open position, C3 prevents the trip control pulse to activate relay 2, and the motor will not react to that command. This is done mainly to prevent the forward timer from starting, causing the arm to move away from the neutral position.

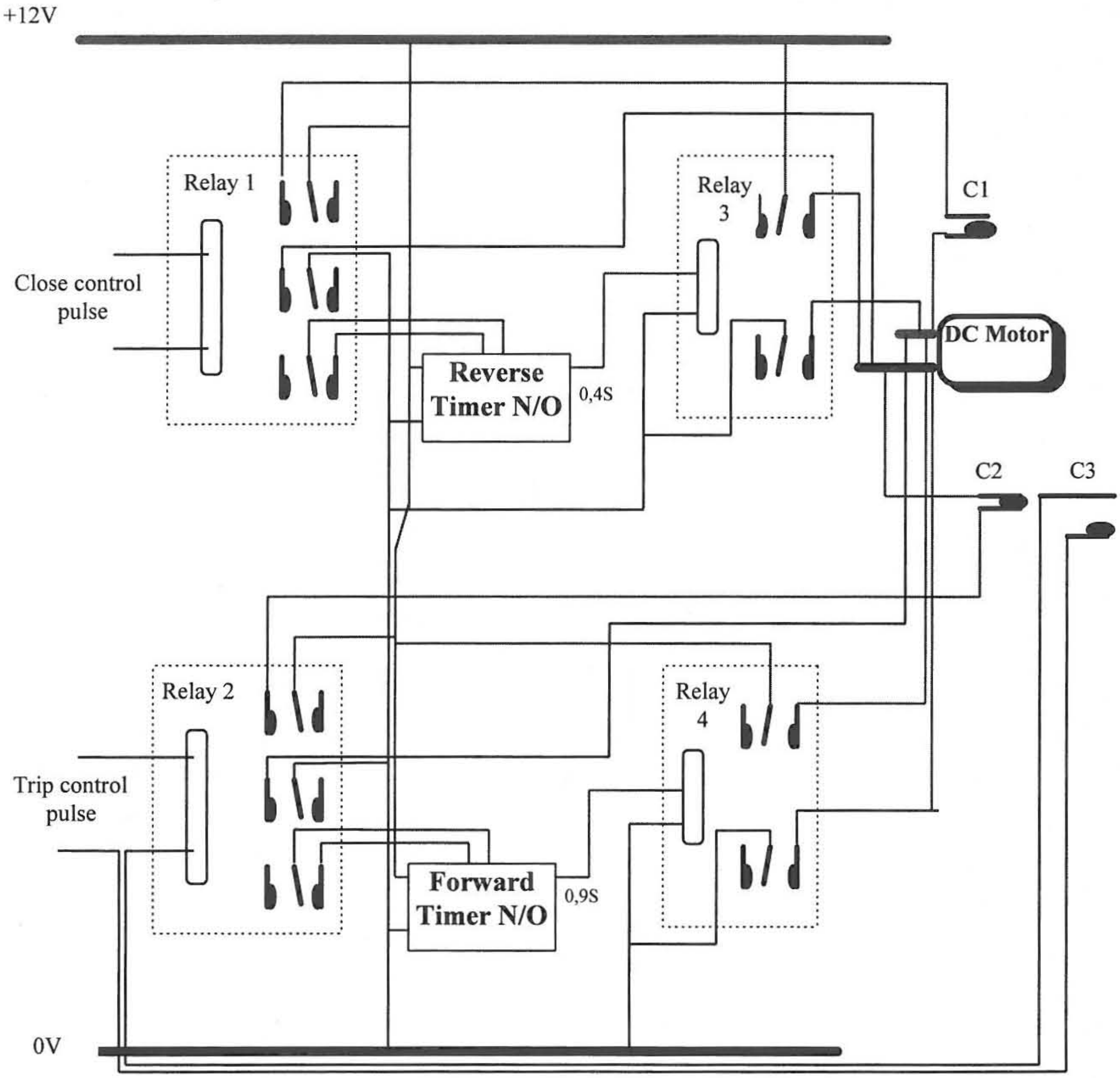


Fig. 6.8: Block diagram of the electronic motor-driver circuit developed to control the reclosers.

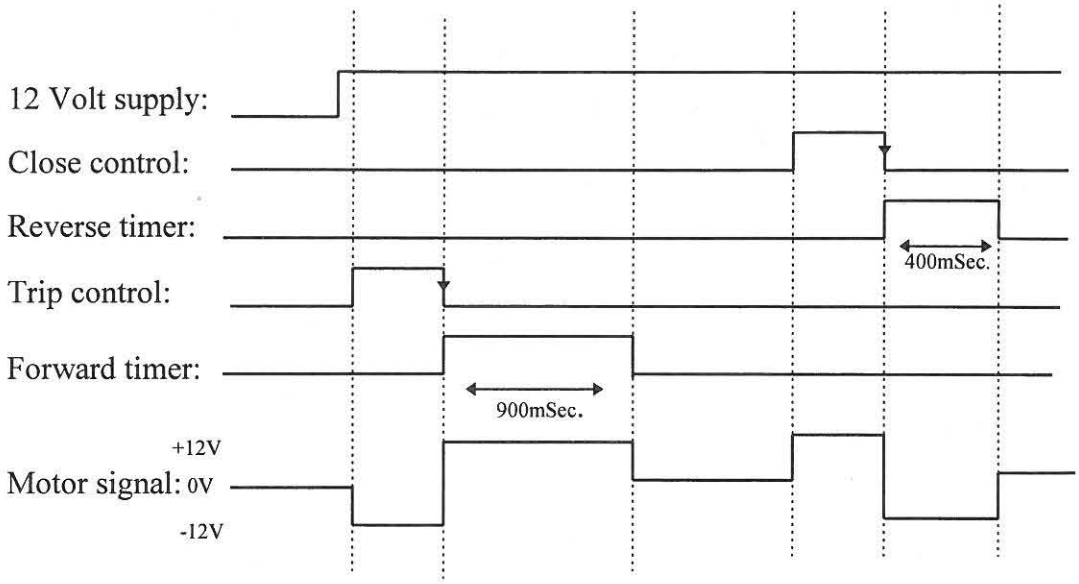


Fig 6.9: Reverse and forward timer operation.

Monostable multivibrators are used in both the reverse and forward mode. Figure 6.9 shows that when a negative-going change in voltage triggers the timer, the output goes high for a fixed time interval. This output is determined basically by a resistor-capacitor timing network, whose values may be selected externally. Figure 6.10 shows the circuit diagram of the monostable used for the timing of the electronic driver.

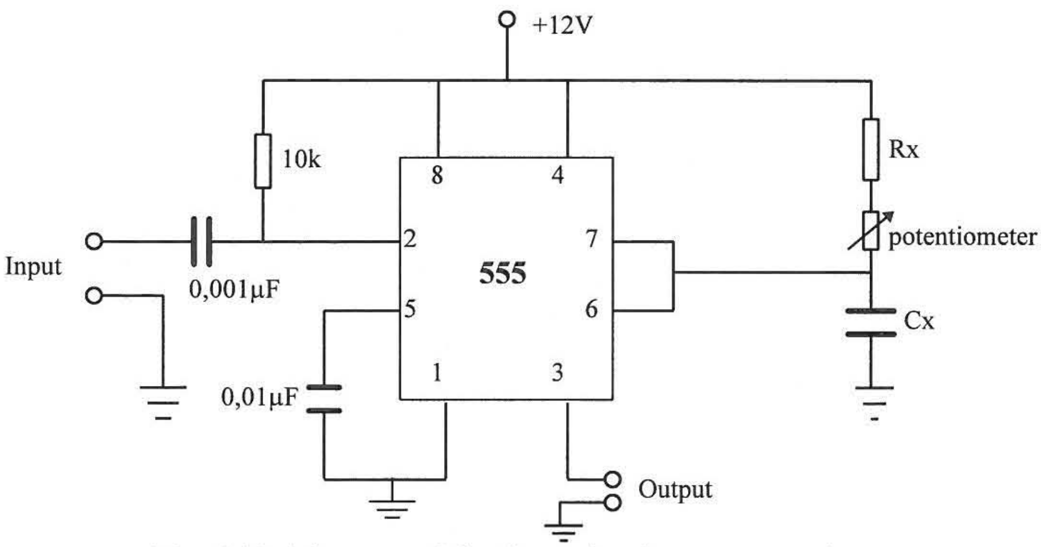


Fig. 6.10: Diagram of the timer circuit.

Limitations: 1k ≤ R ≤ 10M;

and 0,001µF ≤ C ≤ 150 µF

If T = 1,1.R.C (seconds)

and the capacitor used is a 5µF capacitor,

Then 400mS = 1,1 R X 5µF

R = 72,72kΩ, AND C = 5µF (for use in the reverse timer of 400mSec).

Therefore a 72 kΩ, and a 4,7µF capacitor was used.

The forward timer is active for 900 mSec.

Then 900mSec. = 1,1R X 5µF.

R =163,64kΩ, AND C=5 µF.(For use in the forward timer of 900 mSec).

Therefore a 162 kΩ, and a 4,7µF capacitor was used.

6.3.2 Remote close (KFE type).

Closing from lockout can be accomplished manually by moving the handle up to its closed position. Remote closing of the recloser was attempted by the following methods:

① With the aid of the remote-closing motor-accessory, as described in section 6.3.1: This method seems to function very well on both the trip and close commands.

② Replacing the closing solenoid with a low-voltage solenoid accommodates low voltage closing. Experimental tests have shown that in order to function satisfactorily the voltage rating of the coil may not be less than 110 Volts. Because most MRTUs units only have a 12 volt source, this option was not practical. Another disadvantage of this method was that the recloser had to be opened physically in order to install the solenoid. The aim was not to modify any recloser itself, and hence this option was not considered to be effective.

The motor option seems to be the only solution at this stage, and entails the following (see figure 6.8):

When the remote-close motor-accessory is energised from the 12 Vdc supply of the MRTU, it initiates a closing operation by moving the recloser's manual operating handle to its closed position. This actuates the closing solenoid contactor to energize the solenoid and close the recloser.

The 12 Vdc motor mounted on top of the lockout handle case can be used to lift the lever to the closed position, in order to close the recloser. The dc motor receives power from the electronic circuit installed next to the MRTU. This circuit provides the necessary signals to put the motor in forward or reverse motion, depending on the signal received from the control centre, as described in section 6.3.

On the close command, the motor arm moves from the neutral position, clockwise, to lift the yellow operating handle of the recloser, causing the recloser to close. After completion of the command, the arm moves back to the neutral position, and remains in this position until further commands are received.

When the master station sends a close pulse, the MRTU activates the control relay, sending a 12 Vdc signal to relay 1 (see figure 6.8) of the electronic circuit. When the relay energises, a 12 Vdc signal is supplied to the motor. The motor operates clockwise, lifting the yellow operating handle, and closes the recloser. The normally closed contact of C1 is then opened by the motor arm, preventing labouring of the motor in case the duration of the close signal is prolonged. The motor is de-energised until the 12V signal disappears, and the reverse timer starts. This timer sends a 12V reversed polarity signal to the motor, via relay 3, moving the arm anti-clockwise to the neutral position, while the operating handle remains static. The handle can now be operated manually or electrically if necessary. The arm does not interfere with the regular operation of the breaker, because it is moved away, to the neutral position. When the timer completes its cycle, the 12 Vdc disappears, and the arm remains neutral.

6.3.3 Remote trip (ME types).

The manual control switch on the electronic control panel enables manual tripping of the recloser. This is achieved by turning the manual operating switch (figure 6.11) anti-clockwise, causing the trip circuit to activate the electrical circuit of the recloser, and force the recloser to the lockout position.

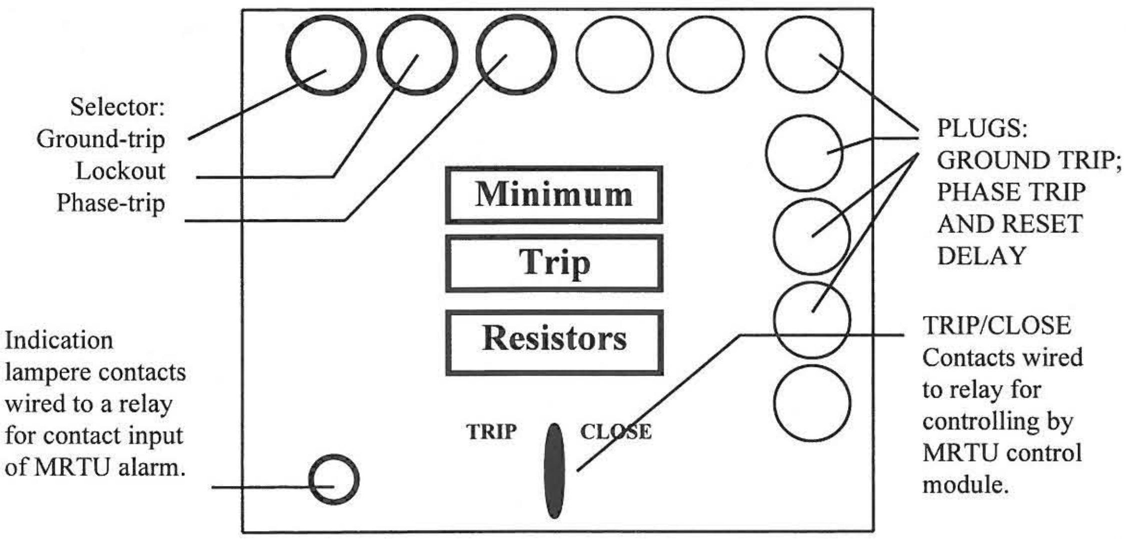


Fig. 6.11: ME recloser panel layout.

A relay circuit was developed to facilitate supervisory control of this type of recloser. The relay circuit connects to the terminal block where the manual switches are coupled.

The manual switch is bypassed by means of these relay contacts, to operate the recloser via telecontrol. This method appeared to be successful, and was implemented. Figure 6.12 shows a block diagram of the relay circuit developed by the author for this purpose. (The detailed circuit diagram can be found in Appendix C).

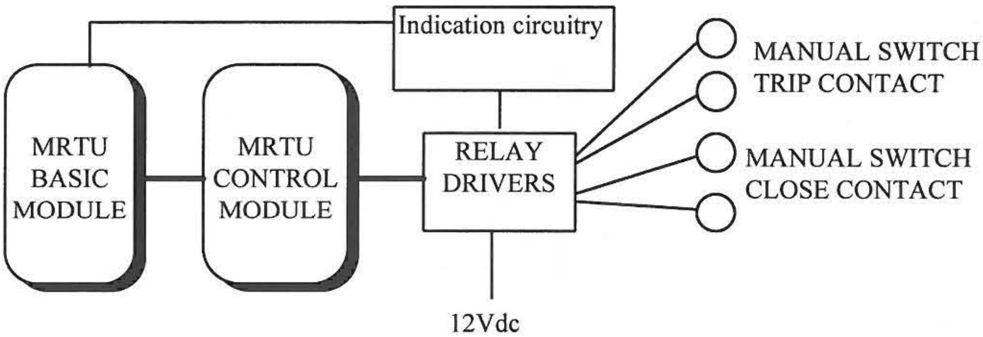


Fig. 6.12: Relay driver circuit, developed for type ME reclosers.

6.3.4 <u>Remote close (ME types).</u>

The manual control switch on the electronic control panel enables manual closing of the recloser. By connecting a relay circuit such as described in section 6.3.3 to the terminal block where the manual switches are coupled, the manual switch can be bypassed by means of relay contacts to operate the recloser via telecontrol, as shown in figure 6.12.

6.3.5 Remote trip and close (4C type).

This type of recloser is manufactured with supervisory facilities, working on 48 Vdc. The relays of the recloser on the electronic board have to be replaced with 12 volt relays, as some of them are 48 - 110 volt relays. The MRTU control output module relays, and the alarm inputs can be directly coupled to the supervisory input/output board contacts, to control the recloser, and do not require any interface equipment. The MRTU control relays are suitable for closing this device, if coupled to the recloser electronics.

6.3.6 Remote trip and close (RV types).

This recloser has no electronic circuitry, and can only be tripped by the yellow operating handle. This type of recloser can be opened by the use of an electrical motor to pull down the lockout handle via the MRTU, as described in section 6.3.1. This recloser can only be closed by the use of an electrical motor to push upwards on the lockout handle via telecontrol.

By implementing these methods, all the reclosers in the Free State distributor can now be controlled via supervisory. In order to provide full SCADA, the indications, alarms and analogues of the reclosers also had to be accommodated.

6.4 Indications on reclosers.

In order for the operator at the master station to determine whether the recloser is closed or opened, remote indications of the recloser must be supplied to the MRTU basic module. Alarms showing the state of the battery and solar system, recloser switch settings and MRTU condition must also be available to the controller at the master station. This is achieved by the following methods:

6.4.1. Indications (type KFE and RV).

Remote indication of the recloser contact position was accomplished by using existing connection locations in some of the electronic junction boxes, when available, or by mounting micro-switches on the side of the recloser mechanism frame. External circuit connections were designed to be contained within the accessory box, and indicated the following:

⇨ *Breaker trip and lockout:* This indication shows whether the breaker is in the open or closed position. The indication is supplied to the MRTU basic module by mounting a normally open micro switch at the bottom of the yellow operating handle. This switch is closed by the handle, if the breaker is in the lockout position. The trip indication of a recloser is normally ignored, because reclosers typically trip and close a number of times during bad weather conditions, without a lockout condition. Unnecessary radio traffic would arise if these conditions were not ignored. Operating staff are also disturbed by unwanted information, as this information is not of interest and most of the faults are cleared before the lockout condition appears. Therefore, lockout condition of the recloser is shown at the master station as a recloser trip and lockout indication. The close indication of the recloser is ignored, because the recloser can only be in the closed or the open position, and not in both positions. Hence it is assumed that if the recloser is not in the lockout position, it is closed.

⇨ *MRTU door opened:* This indication shows that someone is working on or interfering with the MRTU. The alarm is sent to the MRTU basic module by means of a normally closed sensor switch. This switch is mounted on the

MRTU cabinet door, indicating a closed contact when the door is open, and an open contact when the door is closed.

⇨ *Battery alarm:* This alarm indicates the condition of the battery, and is sent to the MRTU basic module from a normally opened contact at the solar panel regulator. It also shows a battery low LED indication if the battery voltage reaches a predetermined low level.

⇨ *Supervisory isolated:* This alarm shows ON if the MRTU is permitted to perform controls on the recloser, and shows OFF when someone is working on the recloser to prevent the recloser from being operated via supervisory.

In order to supply this protection facility, a circuit was developed to prevent the MRTU from controlling the recloser in case of maintenance or other work being performed on the recloser. This prevents the unnecessary exposure of maintenance staff to possible electrical accidents. The SIS (supervisory isolating switch) is used for this function. Figure 6.13 shows a block diagram of the supervisory isolating protection circuit which was developed by the author for this purpose:

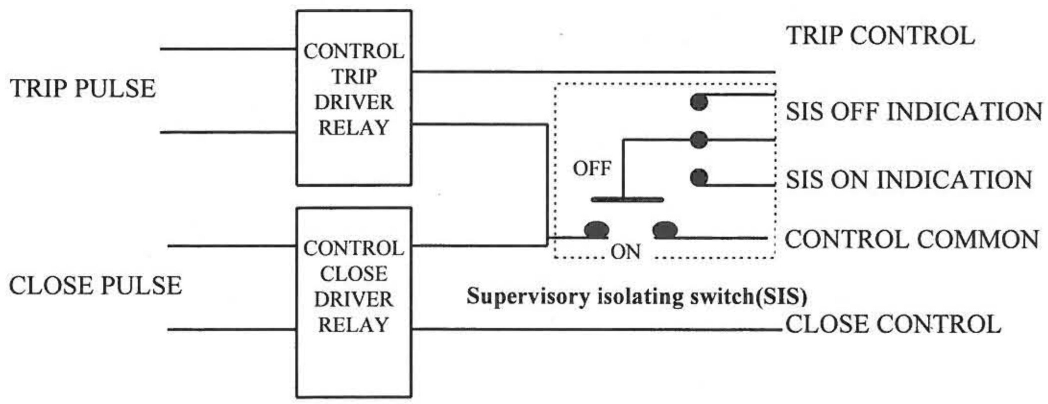


Fig. 6.13: Supervisory isolating protection circuit.

⇨ *Control executed*; This signal shows that the control pulse has been received from the master station, and that the control action was performed by the control relay of the MRTU. This indication is supplied from the control common relay contact, situated in the MRTU basic module, as shown in figure 6.14.

⇨ *Control call from unit*: If working staff wish to communicate with the control centre, via the MRTU radio, this alarm is generated in order to obtain the attention of the controller. A toggle switch is mounted inside the MRTU cabinet for this purpose.

⇨ *Sensitive earth fault on or off*: This indication shows whether the recloser is set to operate on an earth fault that may occur on the power line. According to Van de Merwe [21, p. 4], earth fault protection used for the detection of conductors laying on the ground with small fault currents is very sensitive. This indication is supplied from the electrical box of the recloser, but cannot be supplied for reclosers without electrical circuitry.

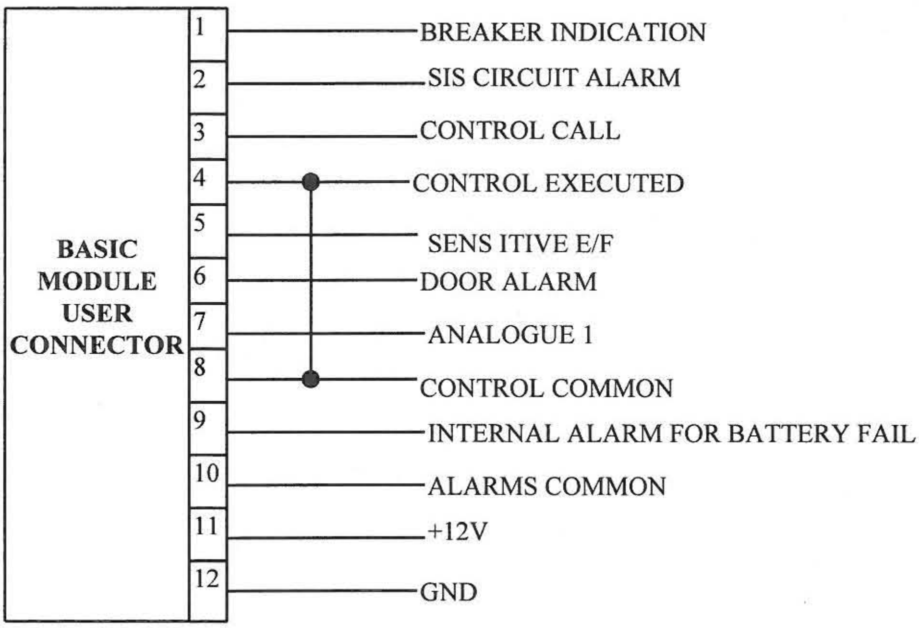


Fig. 6.14: MRTU basic module jumpering diagram.

Figure 6.14 shows the user connector of the basic module, with the outputs connected to the alarms, and the control common coupled to the control execute input.

⇨ *ARC on or off:* This indication shows whether the recloser is set to automatically reclose if a fault condition occurs on the power line.

The ARC relay is activated by overcurrent and earthfault protection circuitry [21, p. 5], and serves to close the breaker after a predetermined time to restore electricity supply in the event of temporary faults. When maintenance on the live power lines is performed, this function is normally used to prevent auto reclosing of the reclosers.

6.4.2 Indications (Type 4C and ME).

The front panel of the recloser is backed by a printed-circuit board, which supports and interfaces the other plug-in circuit boards. The remote control, indications and general accessories were coupled to those points via relays. This is shown in figure 6.15.

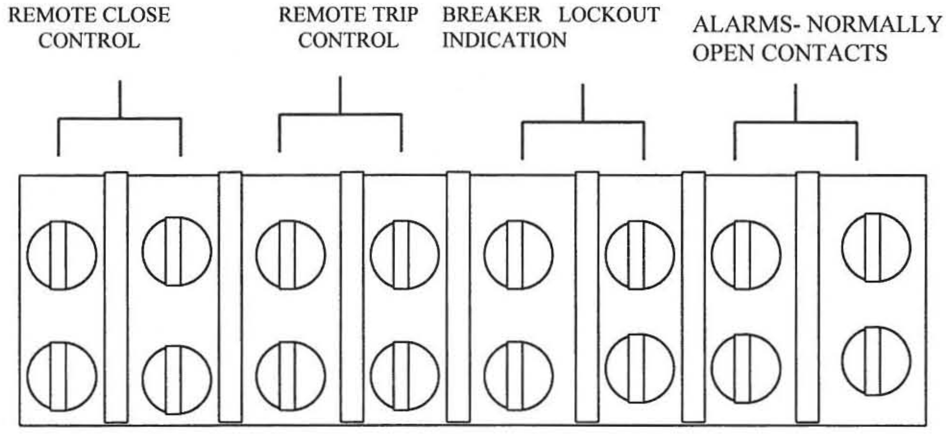


Fig. 6.15: Accessory connections on terminal strip.

The indications of the MRTU basic module is coupled to the connection blocks, which supply the recloser front panel with the alarm indications by means of LEDs. MRTU indications indicating battery alarms, control executed, door alarms and supervisory isolation were done in exactly the same way as described in section 6.4.1.

6.4.3 Analogue readings (all types).

Analogue readings, such as line current, are received from the current transformer of the recloser. The current transformer is described in section 6.1, and a photograph of the current transformer is given in figure 6.2. The output of the current transformer was coupled to a 1 A to 1 mA transducer. If the ratio of the current transformer is 600:5, the transducer supplies a full scale current of 5 mA for the recloser maximum current rating. Therefore, if the recloser current rises to its maximum of 600 ampere, the output of 5 ampere to the transducer will produce 5 mA at the analogue input. The standard analogue input of the basic MRTU module is used to save the installation of an additional analogue module. The basic module is configured for six digital and one analogue indication. If more than six status inputs are configured, an additional analogue module must be added. The analogue reading was calibrated by setting an offset limit at the master station, with maximum alarm limits.

6.5 Modular remote terminal unit (MRTU) assembling.

The MRTU consists of an MRTU basic module, a control module, radio circuitry and actuators. Many of the integrated circuits of the MRTU are of the CMOS (Complimentary metal oxide semiconductor) type. Because of their high input impedance, CMOS ICs are vulnerable to damage from static charges and special care must be taken in handling and servicing these.

CMOS devices can be damaged by improper handling of the circuit modules, even when they are already installed in the system.

6.5.1 MRTU basic module at recloser site.

The MRTU basic module consists of the following circuits:

- ✓ Voltage regulator;
- ✓ User I/O; All I/O lines are protected against surges.
- ✓ CPU;
- ✓ FSK modulator;
- ✓ FSK demodulator;
- ✓ External I/O interface; The external I/O interface provides protection from excessive signals received from alarms and indications at the recloser.
- ✓ Radio interface; This circuit interfaces between the main board and the external Radio Interface board. Diode protection against overvoltage is provided for the channel monitor signal.

Refer to figure 3.3 for a detailed block diagram and schematic layout of the MRTU basic module.

6.5.2 Status display on remote site basic module.

The status display is situated on the front lid of the basic module and it provides a visual indication of the status of the recloser at the remote site. In addition, the status display also provides diagnostic indications for the MRTU basic module.

Status and diagnostic indications are presented on a status display panel that is composed of eight LEDs and a test push-button, as shown in figure 6.16. Each LED indicates the physical status of a dry contact status input.

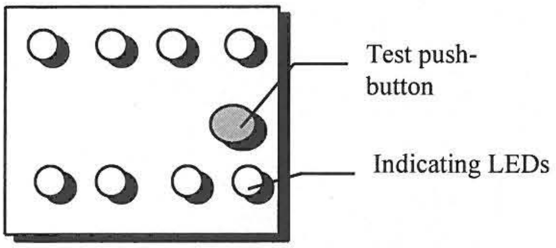


Fig. 6.16: MRTU status and diagnostic indications.

In the MRTU basic module, a LED glows (on) when the status input is closed; the LED is off when the status input is open.

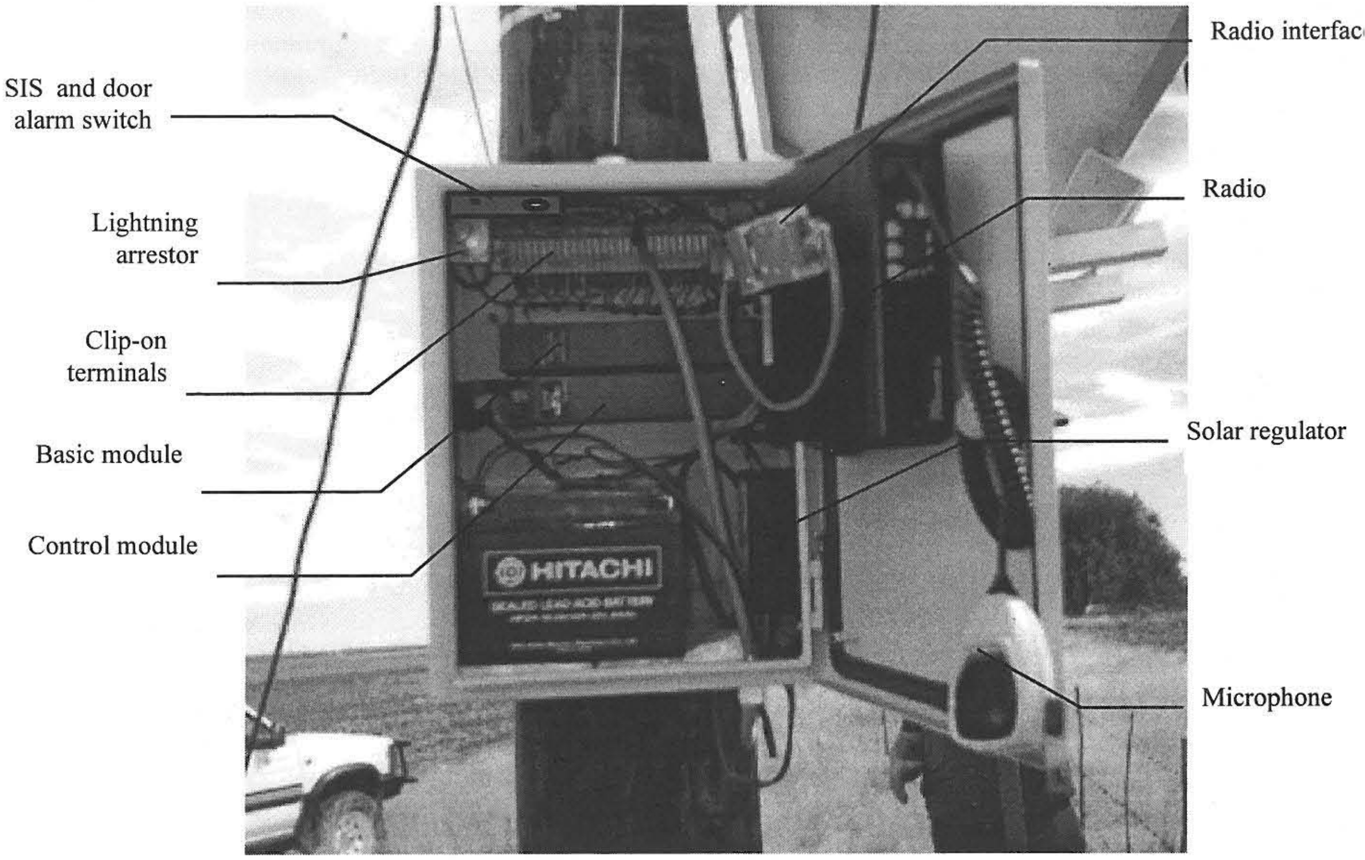


Fig. 6.17: Layout of MRTU unit developed for this project.

6.5.3 Analog inputs.

The analogue input used during this project was configured, at the basic module, by the author. An analogue expansion unit can be added if more than one analogue input is required. The analogue expansion unit is also configured with the MRTU basic module. Such an expansion module monitors a maximum of six analogue inputs and requests. The MRTUs transmit the analogue information to the central station when certain parameter-determined conditions exist. It is housed in its own moulded unit, and may be directly connected to the basic module by means of the bus connector. The MRTU has been configured to read only one analogue input within the MRTU basic module itself, without adding any additional analogue modules during this project. Though, by adding an additional module, more analogues (6) can be monitored. The encoder of the basic module is responsible for communication of analogue messages to the master station (See Appendix C).

The analogue measurements of the inputs are converted to digital data by the analogue-to-digital converter, and the microprocessor performs the necessary scaling and offset adjustments of the data (See Appendix C). Computations performed depend on the data type that is associated with each input channel. The following three data types are used: [12, pp. 1-4].

- Raw data.
- Integral data
- Derived data.

6.5.4 Radio interface.

The MRTU radio interface board enables connection of the MRTU basic module with various types of radios. The radio interface is mounted on the radio cabinet chassis, located on the door of the MRTU housing, as can be seen in figure 6.17.

Two indication LED's are provided, viz one red and one green. These are located on the underside of the PC board, indicating TX busy or RX busy.

6.6 Conclusion.

An MRTU unit was built with the use of an MRTU basic module, a control module, radio equipment and protection devices. The radio and interface were tested, and all levels adjusted for best performance of the system. After software modifications and configurations were performed on this unit, it was mounted into a separate container at the remote site.

All the relevant points were wired to clip-on terminal blocks, for ease of testing procedures, and to enable disconnection of certain points if necessary. The container was coupled to the recloser by means of armoured cable, with plug-in facilities for ease of maintenance.

The reclosers were adapted and modified to be controlled and monitored by MRTU units. Actuators and electronic circuitry were built to facilitate control of these reclosers.

The motor and electronic circuit method which was developed seems to be the most acceptable and reliable option at this stage. The advantage of this method is that it can be used on most types of reclosers, and also on some sectionalisers, if required.

Control circuitry and protection circuitry were built to add more important functions to the reclosers.

Database configurations at the remote, as well as the master station site was configured, and performed the required functions. The database at the remote site was adapted in order to accommodate the use of an analogue signal without the need to install an analogue module. With this method the alarms were limited to six.

The alarms can be seen on the status display at the recloser sites. This seems to be efficient for the purpose of reclosers. Unnecessary alarms such as recloser trip and close during the recloser's sequence is not used.

6.7 Personal involvement.

Various reclosers were tested locally by the author in order to get a solution which could be applied to all existing types of reclosers in the region. These tests were performed in the telecontrol and metering laboratories.

The tests as explained in section 6.3.1 brought about that a motor assembly actuator was built for controlling certain reclosers.

After completion of the motor assembly, certain problems compelled the author to design and build a motor driver circuit, using timers, relays and micro switches as sensors. This was done in the laboratories, and tested locally before commissioning.

A relay-driver circuit was designed, developed and built in order to provide SCADA to certain reclosers, as described in section 6.6.3. (see fig. 6.12 and Appendix C, figure C1.)

The need for recloser indications compelled the author to design, develop and build a Supervisory isolating protection circuit, as shown in figure 6.13.

After completion, all circuits were integrated in the recloser and MRTU cabinet. The assembled product was tested, and one of the units was installed on a 22kV rural line, where it was commissioned successfully.

A photograph of the complete unit can be seen in Fig. 7.1. Over a period of more than 6 months remote tests were performed successfully from the control centre via radio communication.

CHAPTER 7

EVALUATION

7.1 Laboratory tests carried out during evaluation.

Tests were performed in different sequences and on different reclosers in the laboratories. Success was achieved with local master-to-remote tests with the testing of interrogation requests to all the units. Some of the requests failed initially due to bad communications. After level adjustments, the same tests were repeated, and a 100% success rate was achieved.

During remote-to-master tests, several status changes were sent to the master station from the remote units. The master station received all the changed status indications, and the acknowledge message was received by the remote station, preventing retries. During these tests, only two retries were counted, due to channel-busy conditions.

The analogue changes sent to the master station was performed by inserting a constant current ranging from 1 - 5 mA with a test current injector at the inputs of the analogue module.

The controls from the master station to the remote units were received, and the correct voltage was measured on the relay outputs, at the remote location.

7.1.1 Sequences of laboratory tests.

- ***Master to remote:***

Interrogation signals from the master station were sent to the MRTU, to determine whether the MRTU was responding to the master station's requests. The MRTU radio interface was tested at different levels, and was eventually adjusted to -9 dBm. The auto-interrogation program was enabled at the master station for intervals of ten minutes between attempts. After a period of two days, no communication failure was recorded, and the tests were terminated.

- ***Remote to master:***

Different digital input bits were selected at the MRTU station, to determine whether the master station detected a change-of-state at the remote station, and if such changes were acknowledged. Each digital input was tested several times. The tests were acknowledged, and alarmed at the master station as expected.

- ***Analogues:***

Analogue readings were sent to the master station to determine whether the master station acknowledged the analogues. As only one analogue was configured, different current levels were sent to that specific point. After changing the offset level at the master station, the analogue was calibrated, and was received as required at the master station. The analogue alarm level at the master station was set to 0% and 80% of the full scale value of 5 mA.

Different currents were injected into the analogue point by means of a current injector, and the analogue was tested within and out of the alarm limits. Extremely high analogue readings were sent to determine whether the master would alarm at an analogue out-of-limit. This was tested several times, with good results.

- ***Controls:***

One-shot controls were sent from the OW to the MRTU. The control-execute indication that functions with each control from the master station was received and processed, and voltage readings at the MRTU basic module were taken to see if the MRTU was reacting as expected.

Each control output relay was tested, by measuring the voltage received at that specific point. These tests were repeated several times.

As the one-shot control seemed to promote the execution of erroneous controls, the control at the master station was altered to enable the controller to cancel the control before finally sending the command.

The controls were changed to accommodate a double action, required by the operator. Another function was added, which caused the control command to time-out after a delayed decision of five seconds by the operator.

7.1.2 Local tests on types ME, 3A and 4C reclosers.

The front panels of these types of reclosers are backed by printed-circuit boards, which support and interface the other plug-in circuit boards. The remote control, indications and general accessories were coupled to these points by means of relays.

The 12 V close and trip signals from the MRTU control module were coupled to a driver relay circuit, which supplies 12V to the close and trip inputs. This has the same effect as though the breaker was tripped from the front panel control switch. The driver relay circuit in figure 6.12, shows how the supervisory isolating switches are coupled to the relay circuit. This prevents any control from activating the recloser in the case of someone working on any of the apparatus.

For automatic closing of these types of reclosers, the line voltage was required to operate the closing solenoid. Therefore, the closing solenoid voltage was supplied by means of a back-feed transformer with a low voltage side rating equal to the voltage rating of the available power source, and a high side rating equal to the voltage rating of the recloser (11kV). A 12V signal was applied to the relevant points, and the recloser was closed by this action. This procedure was repeated several times, and proved to be successful.

In order to test the trip control, the recloser was closed by means of the closing switch at the front panel. Controls sent from the master station activated the trip relay. This relay tripped the recloser, and the recloser is then locked out. This was repeated a number of times, with satisfactory results.

The indications on the front panel of the recloser were wired to relay circuits. These indications supply the necessary voltage to activate the relay if an alarm occurs. The normally open contact of the relay was coupled to digital inputs of the basic module.

The recloser was manually closed and opened, and indications to the master station were tested. The alarms were received and acknowledged by the master station. The internal MRTU alarms were also tested, and operated successfully.

After completion of the local tests, similar MRTUs were installed and commissioned at remote stations, and have functioned very well at this stage. For more detail about software configurations, please refer to Appendix C.

7.1.3 Laboratory tests on all other types.

Other recloser types used by Eskom were very similar in operation, and some of these were not available for testing purposes. Laboratory tests were performed on the type KFE only.

The motor unit was installed on the operating handle case. The electronic circuitry and MRTU container were mounted on a separate bench for testing purposes. The necessary wiring was completed, and the solar panel was mounted outside the laboratory.

The MRTU and the electronic circuit were then switched on, and communication with the master station was established. The normally open contact, indicating the state of the recloser was also installed.

The recloser was closed manually, and the indication to the master station was tested. After acknowledgment by the master station, the recloser was opened manually to lockout. The indication was again acknowledged by the master station. This was tested several times, and functioned well.

The recloser was then subsequently opened manually. A close pulse was sent from the master station. The motor was energised, and the motor-arm moved the yellow operating handle to the closed position. The recloser remained closed while the timer circuit was activated to move the operating handle to the neutral position. The closed indication to the master station was confirmed.

A trip command was then sent from the master station, causing the motor to move anti-clockwise, and to force the yellow operating handle to the lockout position. This caused the recloser to lock out, and an indication was received at the master station to show the position of the recloser as locked out. The motor arm was then moved by the timer circuit to the neutral position.

The durability of the motor and electronic circuitry was proved by repeating each of these tests for twenty operations.

After completion of the control functions, the MRTU's internal alarms were tested, and acknowledged by the master station.

A similar unit was installed at a remote site in the region, tested and commissioned, and was left at the site for operational purposes (See figure 6.17 and figure 7.1).

7.2 Remote tests performed on reclosers.

After completion of laboratory tests, several remote units were installed in the region, and remote tests were carried out on the following types of reclosers:

7.2.1 Remote tests on ME, 3A and 4C types of reclosers.

Performance tests were carried out with the MRTUs situated at the Theunissen, Clocolan and Viljoenskroon rural power lines. The MRTU units were switched into the network, and were still operational and commissioned for full SCADA functions at the time that this dissertation was written.

The following tests were carried out on all the units:

- The breaker indications were tested several times. The recloser was tripped and closed manually by switching the manual switch at the front of the recloser's operating container to the required position. The indications were received and acknowledged by the master station.

- Alarms were simulated from the recloser. The recloser was isolated for supervisory functions (bypass), and the indication was handdressed at the control centre, to show that the breaker was on bypass. The SIS (supervisory isolating switch) was set to the OFF position, disabling any possible controls to be carried out by the operators.

  All the MRTU alarms were tested, and acknowledged by the master station.

- The analogues were monitored from the master station. The recloser was energised, and the current flow was measured by means of the current transducer and relayed by means of the MRTU to the master station. This current was received and acknowledged by the master station.

- The breaker was tripped and closed several times by means of the remote telecontrol unit, and the indications were monitored at the control centre. The remote control function was found to operate as required, and the units were commissioned and left at the remote sites to monitor and control the pole-mounted circuit breakers.

7.2.2 Remote tests on KFE types of reclosers.

Performance tests were carried out with the MRTU situated at the Harvard/Antwerp rural power line. The MRTU unit was completely switched into the network, and was still operational and commissioned for full SCADA functions at the time when this dissertation was written.

The following tests were carried out on all the units:

- The breaker indications were tested several times. The recloser was tripped and manually closed by moving the operating handle with the aid of a high-voltage isolating rod. Indications were received and acknowledged by the master station.

- Alarms were simulated from the recloser. The recloser was isolated from supervisory functions, and the indication was received at the control centre. The operator at the control centre was not able to perform control functions, and the SIS circuit developed for this purpose seemed to operate well.

  The MRTU alarms were tested, and acknowledged by the master station.

- Analogues were monitored from the master station. The recloser was energised, and the current flow was measured by means of the current transducer. The current reading was then received and acknowledged by the master station.

- The breaker was tripped and closed several times by means of the remote telecontrol unit, and the indications were monitored at the control centre. The remote control function operated as required, and the unit was commissioned and left at the site to monitor and control the pole-mounted circuit breakers.

7.2.3 Problems experienced during the remote tests.

Commissioning tests were performed on a number of units, similar to those described in section 7.2.1 and 7.2.2. However, some signals were not received at the control centre. The problem was due to bad communications as a result of unsuitable antennas being used. In the Clocolan area, best results were obtained with a Yagi antenna, and the communication problems were solved.

7.3 MRTU installation and commissioning.

As the installation of one of the type KFE reclosers was implemented successfully, the unit was commissioned for full SCADA functions. Other types, such as the ME, the 4C, and 3A were also commissioned by the technicians, and have functioned well.

During the commissioning phase, the bypass links of all pole-mounted breakers were closed to prevent any power failures to the customers. The breaker was manually opened and the indications were received by the master station. The recloser was then closed manually, and the indication was received and acknowledged by the master station. In total this sequence was repeated three times for each recloser.

As no actual recloser alarms on the type KFE recloser occurred during the period of test, alarms were simulated, received and acknowledged by the master station. This was also repeated several times, and all of the status changes were received and acknowledged. The analogue input was connected to the transducer and the bypass link opened, causing current to flow through the recloser. An analogue value was received at the master station, and was tested as being within or out of limits. This enabled the control centre to produce analogue trends of certain reclosers. A program was written to extract data within time slots, in order to compile the data to work on standard Excel or Quattro Pro programs.

When all status and analogue changes had been tested, the bypass link was closed again, and the operator at the master station issued a breaker-trip command. The breakers tripped and locked out as expected. The open indication was received at the master station, and acknowledged. The close command was sent from the master station to close the breakers, and the breakers responded accordingly. The same tests were repeated several times, and the breakers tripped and closed as expected.

This completed the commissioning phase of the unit, and it was left in place for operational purposes.

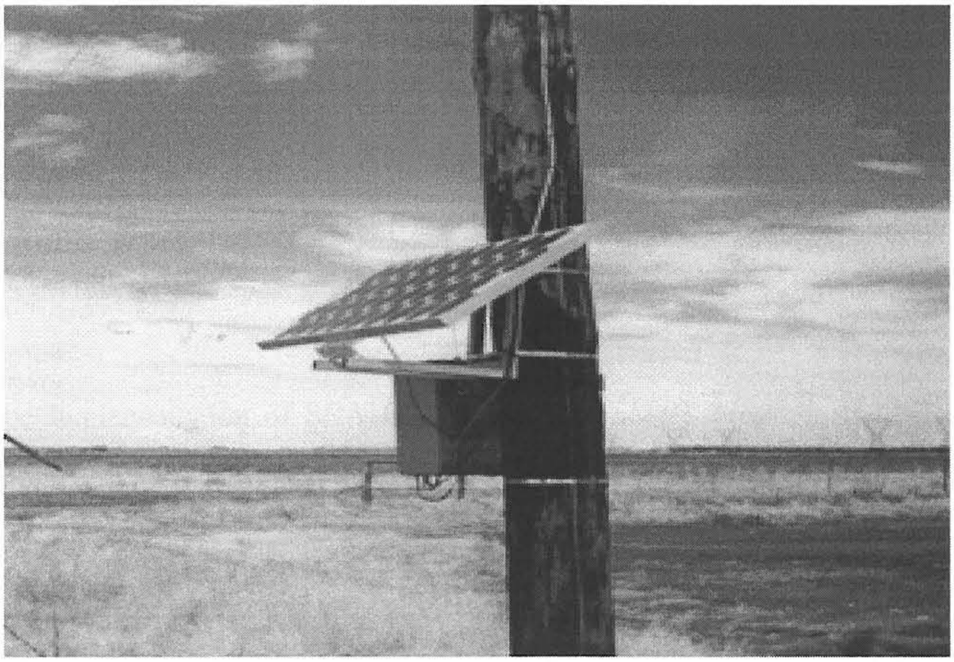


Fig. 7.1: Commissioned telecontrol unit at site.

Twelve similar units were installed in the region, at Clocolan, Vrede, Tweefort, Warden, Frankfort, Clarens and the Klerksdorp area. The units were installed, commissioned and tested thoroughly.

7.4. Conclusion.

The experimental results showed that with the aid of external electronic circuitry and actuators it was quite feasible to provide SCADA to pole-mounted circuit breakers. The financial implications of using the methods described during this research can lead to cost and time savings within a short period of time.

The electronic components used were inexpensive when compared to the costs involved in obtaining information at the desired location. Because much of the electronic circuitry is presently available, the number of uses to which this technology can be applied surpasses the productivity of those who understand the details of telecontrol and electronics.

The use of the motor-driver option opens the field of SCADA on various types of reclosers and sectionalisers, as driving equipment always hindered the use of SCADA on this type of apparatus.

With the implementation of SCADA to the pole-mounted breakers, the safety of personnel, plant and equipment can be enhanced with effective continuity of supply and economy of power systems operations. The continuity of supply on the power system can also be improved without increasing operational costs. The station and field operations personnel though, will always have the final responsibility for the safety of plant and equipment.

With this project, the development of the telecontrol unit for pole-mounted breakers contributed to the overall viewing of the power network at the control centre, as only part of the network was previously available. Before the implementation of SCADA on pole-mounted breakers, a complete view of the network was lacking, and information was dependent on consumer complaints to determine whether the line was energised or not.

Since the reclosers were in operation, their availability for testing purposes was a problem, but with the time and funds available during this project, the aim to monitor and control these devices was attained. With more funds, and the availability of reclosers to be tested locally for a longer time period, other means of reaching this goal could also be investigated.

The constant aim during this research was to develop a practical unit, to meet the required performance for the present and the future, making use of available skills and equipment, at an acceptable cost.

As the option to control certain types of reclosers by modifying the internal electrical circuits was not successful, the option of using actuators seems to be the only solution. During this project the use of the motor and driver circuitry proved to be successful, and the practicality of implementing SCADA to pole-mounted breakers was proven.

I sincerely hope that this project will encourage more investigations in the field of pole-mounted breaker telecontrol, and that this will only be the initial stage of pole-mounted breaker telecontrol developments now, and for the future.

CHAPTER 8

SUMMARY

An overview of the electricity supply network, and the categories of power distribution systems were given in chapter 1. The types of faults occurring on the rural systems, and the apparatus used in order to protect against these faults were discussed briefly, in order to introduce the reader to the operation of reclosers.

The introduction to the recloser consisted of the definition thereof, as well as the operating procedures and the aim of this project (i.e. to control the reclosers). The mobile-radio communications network, its possible advantages to telecontrol systems and the telecontrol traffic system was explained.

Some reclosers were not designed for telecontrol features, and this necessitated modifications on the reclosers in order to permit control by means of telecontrol.

The need for a master station was explained, and the way the remote unit communicates to the master station through secure digital codes and computer languages explained that different units used different protocols. The concept of a LAN system was described as a means to accommodate the integration of communications, planning and office automation.

The characteristics of multi-user systems, types of message exchange and data protocols introduced the reader to the 32-bit protocol used by this unit, which was developed to apply SCADA to reclosers.

Three types of high voltage switchgear, the recloser, sectionaliser and the air-break switch used by the power network were discussed, as these would be affected by the SCADA units which would be developed.

The operation of the MRTU message by means of code words was discussed. Investigations on the working of the MRTU module, and the capacity of MRTUs that could be added to the system were outlined in this chapter. The techniques of positioning the MRTUs, and the installation and dismantling methods of these units were investigated. The control module added to the MRTU basic module to handle the controls was also investigated and described.

Various methods of power supply were investigated, with the conclusion that the solar panel seemed to offer the best solution. Radio requirements, and the choice of radio was also examined. The radio antenna, and the effects of ground on antennas, the destructive effects of lightning, and lightning protection methods were also considered and were investigted.

The dissertation also described the CIU as part of the master station's communication system, and showed how the CIU acted as the interface between the LCU and radio.

The system clock, the operation of the watchdog timer's reset functions were tested during this research.

The use of master station hardware, such as the line control unit and operator workstations to implement the database configuration for use by the MRTU was investigated. Explanations of database configurations that had to be performed on the master station, in order to implement SCADA to the reclosers were offered.

Alarms were configured in order that the operator may receive an audible as well as a visual alarm. The alarm state was shown with colour codes. Basically, a red indication was configured to represent an alarm condition, and a green colour for the normal state of equipment, except for the state of the recloser. The red indication showed that the recloser was closed, and green showed it as locked-out. The OW's graphic displays are pixel based, with moveable windows, and certain symbols were created to display the alarms and indications.

The MRTU detail display was configured to provide symbolic and tabulated indication of the status of the recloser, with a uniquely developed database, especially designed for the purpose of this project.

The LCU interfaced the OWs to the MRTUs. It incorporated a Windows based MMI, and consisted of a PC, which communicated with the OW by means of serial channels.

Configuration on the LCU enabled the LCU to scan the MRTUs at predetermined time intervals. The configuration of the LCU was done, and divided into defined stages that enabled the configuration to be changed at any time.

Chapter six dealt with the remote accessories built to incorporate SCADA on reclosers. The different types and operation of reclosers were discussed in order to explain the modifications done to facilitate control and monitoring of these units.

On the types KFE and RV, it was shown that this type of recloser could only be operated by moving the operating handle. This was accomplished remotely by means of external circuitry and motor drivers fitted on the handle case. The electronic circuit was built in such a way that the motor did not interfere with the manual operation of the recloser.

On the other types, the ME, 3A and 4C, it was proven that the reclosers could be controlled and monitored by means of external relays coupled to the unit's electronic circuits. The complete wiring and diagrams of the circuits built was shown. This modification, as well as the assembly of the most reliable and available unit, accommodated SCADA to be implemented on any recloser.

The indications and modifications done to visualize the status of the recloser was also explained by means of diagrams. The visual status display of the MRTU, the analogue module functions as well as radio interface used and wired into the remote station cabinet were also shown.

Evaluation of the system was discussed in chapter seven. This was done by means of laboratory and remote unit tests.

During laboratory tests on the systems, it was proven that the MRTU unit communicated with the master station, and vice-versa. The master station received all the alarms, and the control functions were received at the remote units.

During installation tests of the units they performed successfully at the remote sites, and were then commissioned and left for operational purposes.

The main contribution of this project is that it has been shown that SCADA for pole-mounted breakers is practical, and that the reliability of the rural power system can be improved by its implementation.

Since evaluation tests have shown that the system performed as planned, the aim of a practical development, to meet the required performance, was realized.

8.1 Summary of involvement in project.

8.1.1 At the control centre.

At the control centre, the existing master station was adapted by the author to provide SCADA to reclosers. This was done as follows:

❋ The installation, wiring and commissioning of a CIU.

❋ Hardware wiring on the Main and Backup LCU.

❋ Configuration changes via Laptop PC on store an forward modules.

❋ Software configuration changes at the LCU using LCU software.

❋ Skeleton drawings drawn at the Server using Sentinel software.

❋ Database configurations at the Server using Sentinel software.

❋ OW's configurations at the OW's using OS/2 and Sentinel software.

❋ Linking of database and skeletons at the Server using Sentinel software.

❋ Execution of domains for different regions using OS/2.

8.1.2. At the remote side (MRTU or recloser side).

At the remote site, an MRTU was developed by the author to provide Supervisory controls and indications to the control centre via radio channels. This was done as follows:

❋ Development, assembly and installation of an MRTU which consists of a Basic module, radio, radio interface, solar panel, regulator, antenna, lightning equipment and protection circuitry.

❋ Development, design and construction of an actuator to open and close the recloser.

- Development, design and construction of an electronic motor-driver circuit.
- Development, design and construction of relay driver circuitry, protection circuitry and indication circuitry.
- Installation and calibration of a current transducer for analogue purposes.
- Software configuration changes via Laptop PC on MRTU.
- Proper lightning and earthing techniques.

The combination of the actions performed by the author at the control centre and at the remote site realised the control of reclosers and even sectionalisers via telecontrol.

Central University of Technology, Free State

APPENDIX A

LCU SOFTWARE OBJECT ANALYSIS AND DESIGN

1) Receive message control object. [16, pp. 19-20].

This object manages all incoming messages to the plant MRTU's. Incoming messages come from the Comms-processor host interface datalink receivers. The Receive Message Control Object decodes the message, and determines the next course of action.

If the message is an MRTU-generated event message, the appropriate RTU Model will be updated with the message via its process Update method.

If the message is some form of acknowledge or reply, the Receive Message Control object will carry out the updating of the relevant MRTU model if necessary, and remove the waiting message at the head of the transmit queue for that comms processor.

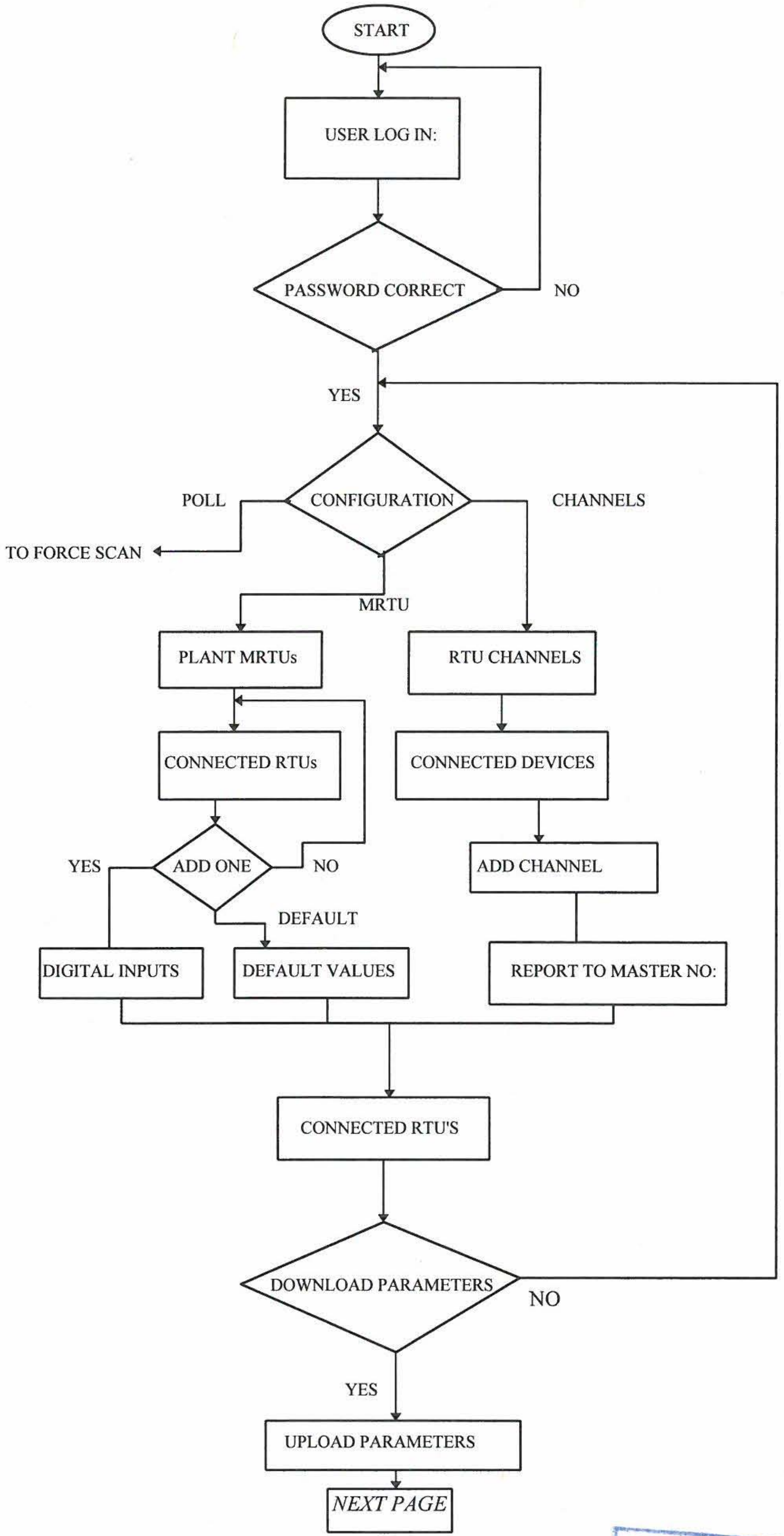
The Receive Message Control responds to the received message by means of the Datalink receiver of the Comms processsor host interface. The message is decoded, and further processing is determined by the type of message just received.

2) Transmit message control object.

This object manages all outgoing messages to the plant MRTU's. It maintains a transmit queue for each Comms processor connected to the LCU.

3.) LCU Configuration.

Software configuration at the LCU was carried out for each MRTU installed by the author. A very brief flow-diagram of configuration changes made on the LCU during the project follows on the next page.


START
USER LOG IN:
PASSWORD CORRECT
NO
YES
CONFIGURATION
POLL
CHANNELS
TO FORCE SCAN
MRTU
PLANT MRTUs
RTU CHANNELS
CONNECTED RTUs
CONNECTED DEVICES
ADD ONE
YES
NO
ADD CHANNEL
DEFAULT
DIGITAL INPUTS
DEFAULT VALUES
REPORT TO MASTER NO:
CONNECTED RTU'S
DOWNLOAD PARAMETERS
NO
YES
UPLOAD PARAMETERS
NEXT PAGE

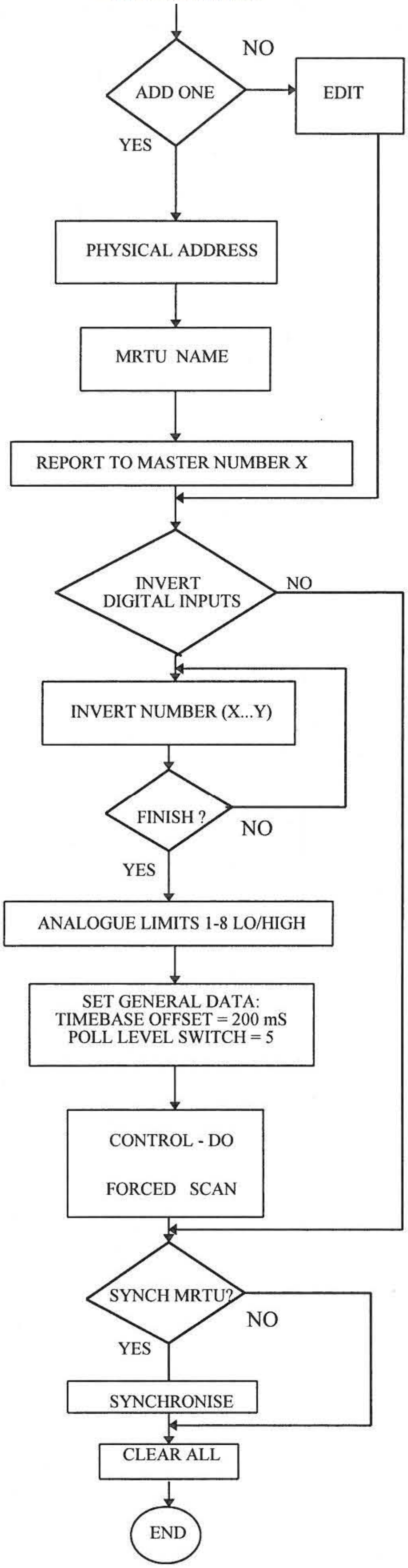


Fig. A1: Diagram of LCU programming as explained and carried out by author.

APPENDIX B

CIU SPECIFICATIONS [12, pp. 55-59].

1.1 General.

- External power required: 110, 120, 230 or 240 V ac -15% to +10%, 50/60 Hz, 24 VAC
- Operating temperature: 50 °C (32-120 °F)
- Relative humidity: 0-85% without condensation

1.2 Operations.

Purpose: To provide a means of intercommunication between a computer or a manually operated terminal and a network of Intrac 2000 remote stations.

1.3 Messages received from controller (LCU).

1. *DIRECT WORD*: transmits general purpose data to remote stations.
2. *DIRECT EXECUTE*: transmits control data to remote stations.
3. *DIRECT SELECT*: used in the select and check back mode to verify remote station selection.
4. *DIRECT INTERROGATE*: causes the addressed remote station to transmit its status/alarm or telemetry measurement input conditions.
5. *AUTOMATIC INTERROGATE*: specifies a remote station for autonomous interrogation by the Central Interface Unit (CIU); up to five requests can be stored in the CIU's buffer at one time.
6. *DIRECT ACKNOWLEDGE*: causes transmissions from the addressed remote station(s) to cease.
7. *AUTOMATIC ACKNOWLEDGE*: specifies a remote station for autonomous acknowledgment which is carried out whenever the communication channel is free or automatically cancelled after a

predetermined time interval; up to ten requests can be stored in the CIU's buffer at one time.

8. *OVERRIDE*: forces transmission of a direct message to remote station(s) on a busy communication channel.
9. *CANCEL*: cancels a direct message presently being entered.
10. *PARAMETER SETTING*: assigns values for system parameters (wait-for-answer, PTT delay, etc.)
11. *COMMUNICATION CHECK*: requests verification that communication with the CIU is operative.

1.4 Messages to controller (LCU).

1. *RESTART*: indicates that initialisation has taken place and the system's operation is based on manually selected system parameters.
2. *DATA*: indicates the data from one status/alarm group or analogue telemetry group normally transmitted by a remote station upon a change-of-state (COS).
3. *TEST*: indicates the data from one status/alarm group or analogue telemetry group transmitted either due to a manual test at the remote station or in response to direct interrogation.
4. *ANSWER*: indicates the data from one status/alarm group or analogue telemetry group transmitted by the remote station in response to automatic interrogation.
5. *CHECK-BACK*: indicates the messagte from a remote station whose bit configuration should verify a direct select request.
6. *FAIL*: indicates failure by a remote station or by groups within the station to respond to automatic interrogation.
7. *REQUEST INTERROGATION*: requests the next automatic interrogate message after terminating autonomous interrogation of one remote station.
8. *TRANSMIT*: indicates transmission of a direct request.
9. *BUSY CHANNEL*: indicates that a direct request has not been transmitted because the communication channel is busy.
10. *OVERFLOW*: indicates an overflow in the buffer storing messages waiting to be reported to the controller (storage capacity: 25 messages).

11. *COMMUNICATION CHECK*: requests verification that communication with the computer is operative.

1.5 Display panel.

1.5.1 Indicators.

- POWER ON: signifies that the power supply is on.
- COMMUNICATION FAIL: indicates that communication with the host computer has failed.
- ALARM DISABLED: indicates a disabled audible alarm.
- CHANNEL TRANSMIT: indicates the transmission of code-word bursts to remote stations.
- CHANNEL BUSY: indicates a busy communication channel.
- COMPUTER DATA OUT: verifies that data is being sent to the controller.
- COMPUTER DATA IN: verifies that data from the controller is entering the unit.

1.5.2 Pushbutton:

ALARM RESET: momentary depression will reset the audible alarm while depression of more than five seconds will disable/re-enable the alarm.

1.6 LCU interface to CIU.

Type: EIA standard RS-232-C: seven-bit ASCII code, single start/stop bit with odd parity; full duplex.

Baud rates: 300, 600, 1200, 2400, 4800 and 9600 Bd

1.7 INTRAC 2000 network interface.

System capacity: Up to 2048 remote stations per rf channel. The total number of remote stations per rf channel can be divided as follows:

- 4 systems with 512 remote stations per system
- 8 systems with 256 remote stations per system
- 16 systems with 128 remote stations per system

Each station has up to eight groups of status/analogue data and up to eight command groups. One group of status/alarm data consists of eight status/alarm inputs or one ten-bit analogue measurement; one command group consists of eight commands.

Transmission method: Two position, pulse duration frequency-shift keying (FSK) over radio or wire-line.

FSK frequencies	1500 Hz ± 2% space	or	1714 Hz ± 2% space
	900 Hz ± 2% mark	or	1028 Hz ± 2% mark

Word format: 32 bits: 26 bits of information, five bits of cyclic code and one parity bit.

Word security: Frame synchronisation check at the start and end of each word

- Bit count check (overflow, underflow)
- Bose-Chaudhuri cyclic code check (five bits out of 31)
- Overall parity check
- Minimum bit duration check
- Word duration: 80 ms typical

1.7.1 Radio interface.

- Input impedance: 600 Ω or balanced high impedance
- Input protection: DC blocked up to 350 V dc
- Input level: +12 to -24 dBm, adjustable
- Output impedance: 600 Ω or balanced high impedance
- Output protection: DC blocked up to 350 V dc
- Output level: +12 to -24 dBm, adjustable

➻ PTT output: Dry contacts (1A, 250 V) or open collector (+30 V/200 mA maximum)

➻ Transmitter warm-up time: 10, 100 or 500 ms with printed board selection switches or variable when under controller selection.

➻ Channel monitor: Dry contact, 2,5 kΩ maximum line resistance.

1.7.2 Device Selection.

1. The address range specified is in the address block 0000-3FFF.
2. Full decoding of these addresses is performed within the MPU.
3. The selection signal of the RAM consisting of U7 and U9 is SRAMA (modification of the RAMA signal).
4. The RAM and the ROM are not installed. These memory devices are reserved for testing or for future applications.
5. PIA registers are selected by the following addresses:

   1000 - Peripheral (or data direction) register A

   1001 - Control register A

   1002 - Peripheral (or data direction) register B

   1003 - Control register B
6. ACIA registers are selected by the following addresses:

   1004 - Control/status register and

   1005 - for the Data register.

APPENDIX C

SOFTWARE AND HARDWARE PARAMETERS

1.1 MRTU parameters.

This chapter entails the software configuration programming carried out by the author at the remote sites. All parameters were configured by the use of a portable computer using the Intrac 2000 configuration simulator programme.

MRTU operation is determined by its physical configuration and by its operating parameters. The parameters described in this chapter was implemented by the author, and was set in the Field Configuration Program (which is an IBM personal computer-based accessory of the MRTU). All data mentioned during this chapter forms an integral part of the success of this project. Wherever relevant, the parameters determining MRTU operation are referred to specifically.

1.2 Ports.

According to Motorolla [12, p. 27], a port number is an internal identifier on each I/O within the common bus. Port numbers are used to identify the expansion modules that are connected to the basic MRTU module via flat cable. The input port number has two characters: the first digit is a number from 0 to 7; the second digit is a letter from A - H. The output port number is a one digit number, from 0 to 7 .

The port number, assigned per module, was set by the author via DIP switches, rotary switches and jumpers.

2. Supported inputs and outputs.

A distinction is made by the author between I/O's belonging to the Basic MRTU module (basic I/O's) and the I/O's belonging to expansion modules. Expansion I/O's include simple status inputs, analogue inputs, relay outputs and analogue outputs. Basic I/O's include status inputs, counter based inputs, analogue input and relay outputs.

From experiece on working with these units, the author found that the basic I/O performs various functions e.g. status, analogue input and relay output. The function of each Basic module input or output was configured by the author at the time of the MRTU configuration. The options were: (8 status, 1 relay), (6 status, 2 relays), (6 status, 1 relay, 1 analogue input - which was configured for the purpose of the project) and (2 counter, 1 run time, 1 pulse frequency).

2.1 I/O reporting mechanisms.

In general, two mechanisms was configured by the author for I/O reporting: Interrogation and contention. Contention is a MRTU initiated transmission that occurs due to one of the following Change-Of-State (COS) conditions:

Status COS - a transition in the state of a status input causes a MRTU transmission to notify the change.

Delta Limits COS - a change in the value of a counter-based or analogue input from the last transmitted value that exceeds a predefined delta limit. The COS triggers a MRTU transmission.

Overflow\Underflow - if an analogue or counter based input registers a reading that is out of scale (overflow or underflow), this triggers a MRTU transmission.

In the event of multiple COS's at a MRTU, it was found during this project that the MRTU initially completed the first COS transmission (including all repetitions or until an ACK is received from the master station). Then the next COS were transmitted. When more than two COS's occured, the MRTU transmitted the first and second COS and then the most recent COS.

The term "interrogation" can be described by the author as a transmission initiated by the master station to any MRTU; the MRTU reports the condition of its I/O's accordingly.

2.2 Time and debounced (2 - inputs).

The MRTU applies two filters which was configured by the author by software on the basic inputs (in addition to the hardware lowpass and surge filter): the time filter and the optional debounced filter.

2.2.1 Time filter.

The time filter parameter was configured by the author to determine the number of samples (taken at 4 msec intervals), which must be identical before the input is considered stable. This was configured by means of a portable computer.

The time filter parameter was set at 20 msec.

2.2.2 Debounced (2 - INPUTS) filter.

An option exists for every two inputs to be coupled into a single debounced. Debounced inputs eliminate false COS reports due to bouncing of input contacts. This is suitable for an input coming from a changeover contact and monitors both the Normally Open (NO) and Normally Closed (NC) terminals. A debounced input has three possible states: primary contact closed, secondary contact closed, both contacts open or closed. The "contacts open" state is a transient state and as such is not reported or considered stable.

During this project it was found that when the input was in the transient state, the last contact state was the valid state of the debounced inputs. The state of the debounced input status is reported by two successive and complementary bits within the configured status group. The debounced function (run time, counter, etc.) was considered the stable state. For example, ripples in one input while the second was stable was considered as only one change. Although this option could improve reliability, it was not configured by the author during this project, but it could be used if certain problems occurred at an MRTU site.

2.3 Basic status inputs.

All the basic status parameters was set by the author via portable computer. For the MRTU, each basic status input was reported as one bit within the configured status group. The logic representation of a closed input within the reported status group was configured via the computer software.

A COS from a status input may be caused by an open-to-close transition (OTC) - {configured for the purpose of this project}, a close-to-open transition (CTO), or any transition (BP - bipolar). If desired, an ignore (I) option disables COS reporting for that status input. This option was not configured.

There is an option to disconnect inputs from the status group by using the Input Connected parameter. The state of the disconnected input will not be updated in the status reported group. This was configured by the author saving the installation of an additional second relay module and analogue input respectively.

2.4 Software settings.

2.4.1 Counter based inputs.

The use of Counter-based inputs was considered, configured and tested for counting the amount of lockouts of the pole-mounted breaker, but eventually it was not used by the author for the purpose of this project.

2.4.2 Pulse frequency.

The pulse frequency function calculates the average pulse frequency registered at a basic input according to user defined parameters, via the portable computer.

The accuracy is 0.1% of the maximum frequency value when the input frequency is in steady state, and the frequency is measured in a window of 4 seconds minimum The calculation of the data before transmission is performed by using one of the following preconfigured maximum frequencies: 1, 2, 4, 5,10, 20, 25, 50, 100 Hz. The author has configured a frequency of 50 Hz for the purpose of this project.

The frequency was reported on one group as a 10-bit value in two's complement format. A COS was caused by exceeding a parameter selectable delta limit.

The delta limit was set by the author at 20% via the portable computer. The actual significance of 0% delta limit is 0.1%; 0% is not recognized. The significance of 100% delta limit is to mask COS transmissions of the pulse frequency input.

The value of 500 to 511 is defined as over-range. This is reported and is used for calibration purposes.

Overflow is indicated by +511. Underflow is not defined for the frequency measurement.

2.4.3 Pulse duration.

The pulse duration input measures the time when the contact at the input is closed in relation to a fixed pulse frequency. The following fixed pulse frequency was configured by the author via the portable computer:

- Type 3/15 pulse (15 sec / cycle)

The method of calculating the pulse duration can be explained with the following:

Transmitted value = (1000/9) x (close duration [sec]-3) - 500 Close duration [seconds] = (9/1000) x transmitted value + 7.5

2.4.4 Run-time counter.

The run-time counter measures the total on-time of a specified device, monitored by an input. The closed state was defined by the Input Closed representation parameter configured by the author on the portable computer. This means that the on-time is accumulated when the physical input either opens or closes, depending on this representation.

2.5 Analogue input.

The MRTU provides one floating analogue input with 8-bit resolution (reported as 10 bits) as part of the basic MRTU module. A COS is caused when the analogue value exceeds the parameter selectable delta limit set by the author. The delta limit is expressed as a percentage of the full range (1000). The delta limit was set by the author at 10%.

The values of +510 and -511 are defined as over-range and under-range values respectively (normal state = +500 and -500). These ranges was reported precisely (in the same way normal values) and was used for calibration purposes during the project.

2.6 Relay outputs.

The relay parameters was set by the author via the portable computer as follows.

2.6.1 Relay type (Momentary, Latched, Common Latched and General).

The MRTU supports operation of relays in Latched, Momentary, or Common Latched mode.

0 | 0 Don't Care
0 | 1 Set Latch
1 | 0 Reset Latch
1 | 1 Momentary (used for this project)

MOMENTARY MODE; The execute command available for Momentary relays as used by the autor is as follows:

Intrac Bits	16	17	18	19	20	21	22	23
	K4	K3	K2	K1	K4	K3	K2	K1
	<- odd port ->				<- even port >			

The relay operation time for momentary relays was set by the author at 1 second.

2.6.2 Comms failure preset and comms fail timer.

The Communication Fail Timer together with the Communication Failure Preset is designed to prevent relay operation by the MRTU that could prove damaging in case of unexpected long periods of communication failure.

The Communication Fail Timer (CFT) was configured by the author via the potrable computer that if within the specific time interval (in this case 350 hours) there is no valid Intrac reception (Execute or Interrogation), the action of Communication Failure Preset action is carried out.

In the event of communication failure, relays that are parameter configured as Communication Failure Preset will be switched to a "0" state. This parameter was set by the author for basic and expansion relays. Latched and Common Latched are preset, while Momentary or General are momentarily set.

2.6.3 Toggle mode.

Toggle Mode Timer parameters are available, but was not used during this project.

3. MRTU Communication.

3.1 MRTU Address.

The MRTU communicates over radio channels with a central station or other MRTUs by means of a digital communication protocol. Each MRTU is identified by means of two addresses: the system address and the station address.

The system address identifies the communication system within a specific radio channel on which the MRTU communicates. Up to four systems can share the same radio channel (system addresses from 0 to 3).

The system address was entered by the author (System =x, depending on MRTU) via portable computer. The station addresses identified the MRTUs (within the system address) in all communications. Up to 512 addresses can be configured (0 - 511).

The master station to remote or central to remote (CTR) station address is the same address that the MRTU uses to receive messages from a master station or to transmit messages.

3.1.1 Central to remote (CTR) communication.

With this address, MRTU's communicate with a master station. Data is reported to the master station and the master station sends control (execute) commands, interrogation and acknowledgement commands.

3.2 Communication parameters.

The communication parameters, summarized in the following sections was set by the author. These parameters determine the communication modes of the MRTU.

3.2.1 NUMBER OF TRANSMISSIONS PER COS (16 times) - Determines the number of transmission repetitions per COS.

3.2.2 TRANSMISSION INTERVAL (20 sec.) - Determines the time interval between repetitions (per COS).

3.2.3 PTT DELAY/WARMUP TIME (500 msec.) - The Field Configuration Program sets the PTT delay/warmup time automatically according to the MRTU model/option numbers:

3.2.4 NUMBER OF WORD REPETITIONS PER BURST (4 times) - Determines the number of times the codeword is repeated in MRTU transmission. The repetitions improve message throughput.

3.2.5 2-SECOND LIMIT ON TRANSMISSION (NO) - Optional parameter which limits MRTU transmissions to two seconds of air time. Was enabled where the FCC 2- second regulation is in effect.

3.2.6 WAIT AFTER 2-SECOND LIMIT (OFF) - Applicable if the 2-second. parameter was enabled. This parameter will apply a delay cycle if the MRTU transmission was stopped due to the 2-second. limit, before beginning the next transmission.

3.2.7 CHANNEL BUSY WHEN CM HIGH (YES) - Polarity of the radio channel monitor (CM) signal determines this parameter. YES is configured if a high-voltage level of CM signal indicates a busy channel. LOW is configured if a low voltage level (ground) of CM indicates a busy channel.
The Field Configuration Program sets the CM polarity automatically according to the MRTU model\option numbers.

3.2.8 CM OVERRIDE (120 sec) - Instructs MRTU to transmit even if a busy channel condition is detected.

3.2.9 RECEPTION CONDITIONED BY BUSY CHANNEL (NO) - If this parameter is enabled (YES), the MRTU will recognize data transmissions only if the CM signal indicates a busy channel; if disabled (NO), the MRTU will recognize data transmissions regardless of the state of the CM signal.

3.2.12 STOP TRANSMISSION IF LOW BATTERY (NO) - If this parameter is enabled, the MRTU will stop transmissions when a low-battery indication is detected.

However, when the internal indication was enabled, the Low Battery was reported once (with the repetitions).

4. Transmission timers.

4.2.1 Periodic (transmission) timer.

The Periodic Timer initiates a MRTU transmission of all groups after the time period specified by the Periodic Timer has lapsed. The Periodic Timer option assures a periodic update of the MRTU data at the master station. This was not configured during this project.

5. Check back before execute and local check before execute.

The Check-Back-Before-Execute and the Local-Check-Before- Execute functions are used in special (electrical) applications, where a very high level of reliability in relay switching is required and was not configured for the project.

6. Change current function parameters.

This function was configured by the author to modify various parameters related to the input functions in the basic MRTU module (parameters such as transmission delta, analogue limits, maximum frequency)

7. Change to simple status.

This function was configured by the author to change the input to a status input.

8. Change to analogue input.

This function was configured by the author to change the input to an analogue input (4 - 20 mA.)

9. OW channel configurations.

9.1 OW identification.

This programme runs in OS-2 and was configured by the author in the "startup.cmd" file to identify the OWs as Domains of the Pole-mounted MRTUs. This was done on each OW in order to allow all OWs to access the

Pole-mounted breakers, as the operator logs in. For the purpose of this document, only part of the programmes are shown.

```
DEVICE=C:\IBMCOM\PROTOCOL\LANPDD.OS2
DEVICE=C:\IBMCOM\PROTOCOL\LANVDD.OS2
SET USER_INI=C:\OS2\OS2.INI
SET SYSTEM_INI=C:\OS2\OS2SYS.INI
SET OS2_SHELL=C:\OS2\CMD.EXE
PRIORITY_DISK_IO=YES
DEVICE=C:\MPTN\PROTOCOL\MPTN.SYS
SET DSPPATH=C:\MMOS2\DSP;
SET NCDEBUG=4000
DEVICE=C:\MMOS2\SSMDD.SYS
DEVICE=C:\MMOS2\R0STUB.SYS
set SENTID=5
set SENTDISK=D:
set SENTDIR=\SENTINEL
DEVICE=D:\SENTINEL\BIN\HASPOS2.SYS
@ECHO OFF
ECHO.
PROMPT $i$p$g
PATH C:\OS2;C:\OS2\MDOS;C:\;
LOADHIGH APPEND C:\OS2;C:\OS2\SYSTEM
SET TMP=C:\
LOADHIGH DOSKEY FINDFILE=DIR /A /S /B $*
DOSKEY EDIT=QBASIC/EDITOR $*
REM SET DIRCMD=/A
```

9.2. Display command setup.

```
@ECHO OFF
VCDPGM %1 %2 > C:\VCDX.CMD
IF ERRORLEVEL 1 GOTO END
CALL C:\VCDX.CMD
:END
DEL C:\VCDX.CMD
```

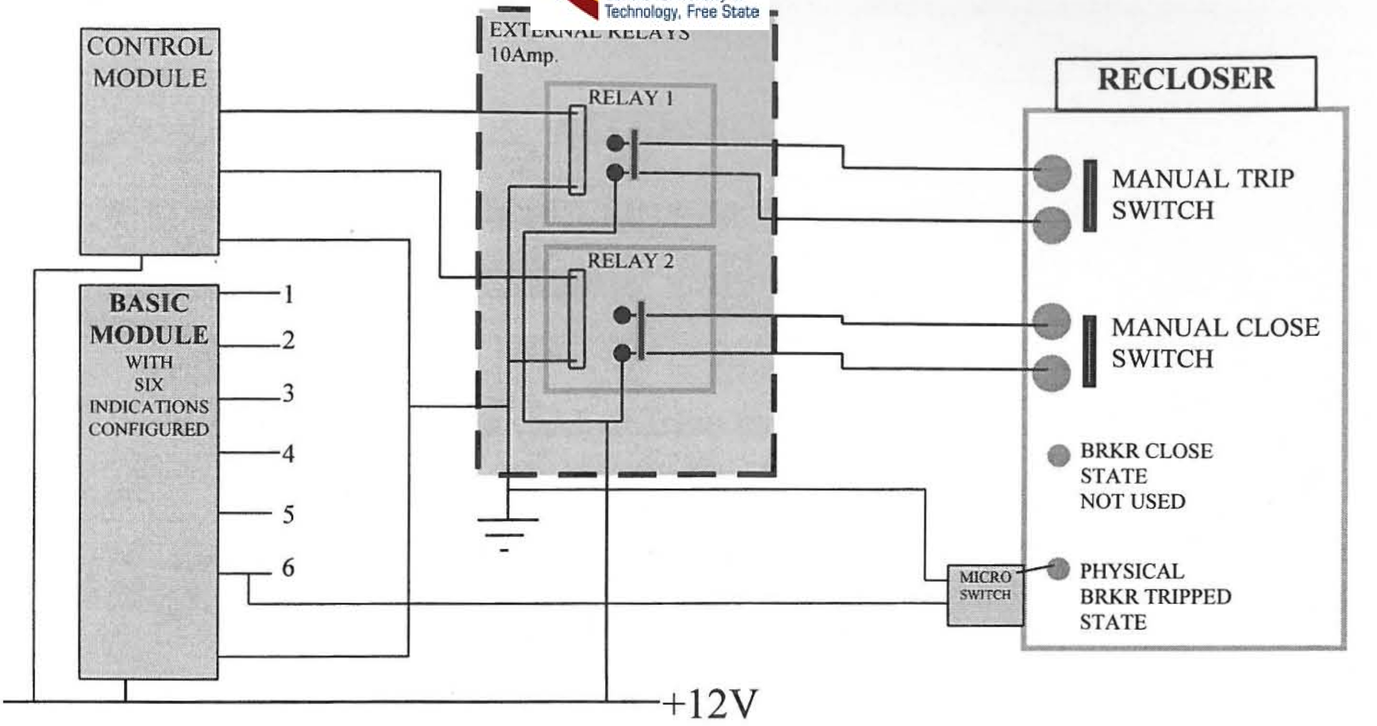


Fig.C1: Relay driver control and indication circuit.

Central University of Technology, Free State

REFERENCES.

1. **ERA Technology**. Lightning Protection: ERA Seminar Proceedings, 1988.

2. **Fink, DG**. Electronics Engineers' Handbook. 3rd ed. New York: Mc Graw-Hill Book Company, 1989.

3. **Gruenberg, EL**. Handbook of Telemetry and Remote Control. New York: McGraw- Hill Book Company, 1967.

4. **Kennedy, G**. Electronic Communications Systems. 2nd ed. Kogakusha: McGraw-Hill Book Company, 1977.

5. **Laughton, M.A & Say, M.G**. Electrical Engineer's Reference Book. London: Butterworths, 1986.

6. **LCU Technical Manual**. Sentinel Telecontrol System. RSA: Halfway House, 1992.

7. **LCU Software Object Analysis and Design**. Sentinel Telecontrol System. RSA: Halfway House, 1992.

8. **Mantell, CL**. Batteries and Energy Systems. New York: McGraw-Hill Book Company, 1970.

9. **Marshall, J.L**. Lightning Protection. New York: John Wiley & Sons, Canadian Broadcasting Corporation, 1973.

10. **McGraw Edison Power Systems**. Reclosers Type KFE 10002-E Three Phase: Service information. USA: Cooper Industries, 1986.

11. **Microsoft.** LAN Manager. Administrator's Guide for OS/2: Version 2.2. Redmond: Microsoft Corporation, 1994.

12. **Motorola Inc**. Intrac 2000 Modular Remote Terminal Unit: MRTU Plus. Schaumburg: Technical Writing Services, 1988.

13. **Motorola Inc**. Intrac 2000 Modular Remote Terminal Unit: MRTU Plus. Schaumburg. Technical Writing Services, 1989.

14. **Myers, JD**. Solar Applications in Industry & Commerce. New Jersey. Englewood Cliffs: Prentice Hall, 1984.

15. **Network Technologies**. Novell Education Course 200. Rev.1. Provo: Novell, Inc., 1994.

16. **Operator Workstation / Line Control Unit Interface and Protocol.** Sentinel Telecontrol System. RSA: Halfway House, 1992.

17. **Raynham, E.F.** Southern African Photovoltaic Market and Applications. Bryanston: Prentice Hall, 1989.

18. **Roberts, S**. Solar electricity: A Practical Guide to Designing and Installing Small Photovoltaic Systems. New York: Prentice Hall, 1991.

19. **Say, M.G**. Electrical Engineers Reference Book: 13th ed. London: Butterworth, 1973.

20. **Strock, OJ.** Telemetry Computer Systems. Instrument Society of America, New York: Mc Graw-Hill Book Company, 1983.

21. **VD Merwe, LW**. Beveiligingshandleiding vir Operateurs. Bloemfontein: Eskom, 1992.