Department of Electrical and Computer Engineering

Internet-Based Monitoring and Controlling
of Real-Time Dynamic Systems

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Abstract

The study in this report mainly focuses on the Internet-based Monitoring and Controlling of a Real-Time Dynamic System interfaced via a dedicated local computer. The main philosophy behind this study is to allow the remote user to conduct an Internet-based Remote Operation (I-bRO) for the dynamic system. The dynamic system has been defined as the system which has its parts interrelated in such a way that a change in one part necessarily affects other parts of the system [1]. In order to achieve this goal, the study has been conducted in a form of an on-line and real-time Virtual Laboratory (VL). Through this form of laboratory, a user can carry out the experiment, perform real-time monitoring and controlling operations of the experiment and collect real and live data from the experiment through the network link as the user was physically in the laboratory. The dynamic system that has been selected for the test-rig of this study is a 3-phase Induction Motor (IM) which is mechanically coupled with a DC-Dynamometer that acts as a variable load to the IM. This system is a common laboratory experiment in the study of the Electrical Engineering for both undergraduate and postgraduate students.

The study covers both sides of the I-bRO; the hardware and the software. The hardware side includes the design and the development of a load control box that has been used to interface the DC-Dynamometer and consequently control it from the local computer. The software side covers the design and the development of the Virtual Instrumentation System (VIS) that has replaced successfully the physical Measurement and Test (M&T) instruments of the test-rig. Beside that, the software side includes the development of the internet remote front panel for the remote operation. Furthermore, the software side includes the development of the software that has been used to analyse the system during the I-bRO. In this study, the LabVIEW7 program has been used to design and develop the VIS and the Matlab program has bee used to analyse the system performance for the remote operations.

This study also addresses the issues and problems related to the intranet or the internet to be used as the network for data communication between the test-rig and remote users. This study has been carried out in different stages as follows:

1. Designing and development of the VIS.
2. Interfacing the test-rig apparatus with a local computer.
3. Upload the system from the local computer to the network.

4. Study the performance of the system on the network for the purpose of the remote operations controlled over the internet

The developed system of this study has been used for data acquisition, network communications, instruments monitoring and controlling applications. A user can execute on-line and in the real-time the developed VIS from any point in the university. Du to the fact that the university network is directly integrated to the main internet server, a remote user through the main internet server is able to perform I-bRO of the selected dynamic system.

There are many factors associated with the network, the internet or the intranet, and have direct influences on the control system performance throughout the remote operations. The most dominant factors are the random time-delays and the data losses. These factors among others have to be addressed for a proper application of the I-bRO. For this reason, different cases and scenarios of the I-bRO have been investigated and simulated to study the affection of the network on the control system performance. The system is analysed under two control cases, closed loop with random time-delays and open loop when the internet server is disconnected and no communication between the input and the output of the system. In the first case, the closed loop, the internet server is assumed to be closed and subjected to random time-delays. In the second case, the internet server is subjected to random cut-off and thus opens the control loop. The results of both cases have been analysed and discussed. It has been found that, if the control system without the time-delays is stable, it remains stable even with small time-delays up to twenty seconds. This result is different from what has been shown in the literature.

Declaration

I declare that, this thesis contains no material, which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

Acknowledgment

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Dedication

This work is dedicated to my wife Safiya, Sons and daughter for standing by with me throughout the duration of this research although sometimes they missed home and loved ones. This for me is the most painful and humbling of all.

To all of them I dedicate this work

Saoud

Perth, WA, **2005**

Acronyms

ADS:	Autonomous Decentralised Systems
AIM-Lab:	Automated Internet Measurement Laboratory
ASCII:	American Standard Commands for Information Interchange
BNC:	Bayonet Neill Concelman
C-bIS:	Computer-Based Instrumentation System
CLTF:	Closed Loop Transfer Function
CPU:	Central Processing Unit
DMS	Distributed Measuring Systems
DSP:	Digital Signal Processing
GPIB:	General Purpose Interface Bus
HPIB:	Hewlet Packard Interface Bus
I-bCS:	Internet-based Control System
I-bIS:	Internet-based Instrumentation System
I-bPC:	Internet-based Process Control
I-bRC:	Internet-based Remote Control
I-bRO:	Internet-based Remote Operation
IEIT:	Institute of Electrical Information Technology
IP:	Internet Protocol
LabVIEW:	Laboratory Virtual Instrument Engineering Workbench
LAN:	Local Area Network
LIS:	Load Isolator Switch
LSB:	Least Significant Bit
MSB:	Most Significant Bit
M&T:	Measurement and Test
NI:	National Instrument
OLTF:	Open Loop Transfer Function
OOP:	Object Oriented Program
OOT:	Object Oriented Technology
PID:	Proportional-Integral-Differential
RPM:	Revolution per Minute
RPS:	Revolution per Second
RS-232:	Recommended Standard 232

RTOS:	Real-Time Operating System
SIS:	System Isolator Switch
SPP:	Standard Parallel Port
SSR:	Solid State Relay
TCP:	Transmission Communication Protocol
TPD:	Transient Protection Diodes
TTL:	Transistor Transistor Logic
UDP:	User Datagram Protocol
USB:	Universal Serial Bus
VI:	Virtual Instrument
VI:	Virtual Instrumentation System
VIP:	Virtual Instrument Platform
VISA:	Virtual Instrument Software Architecture
VL:	Virtual Laboratory
VSPC:	Virtual Supervision Process Control
WAN:	Wide Area Network
WCS:	Web-based Controlling System
WWW:	World Wide Web

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1 Introduction

The internet technology has had significant effects on almost every single aspect of our daily life and has changed the way the people perform their daily works. It made the world appears as a small village in which people communicate with each other, make business, entertain, retrieve information and even the way they educate themselves, as they were physically in the same part of the globe. Internet implementations have moved from the traditional applications such as the e-mail or chatting to the professional applications such as in research and educational centres, industrial plants and medical centres.

Internet-based Remote Operation (I-bRO) is a new technology that has attracted the attention of different developers and researchers in different fields. Since the invention and the spread of the internet, great efforts have been made to integrate the remote operation with the internet technology. Some of these efforts have succeeded and consequently different systems have been developed and operated. From the literature, most of the developed I-bRO systems are in forms of internet-based robotic systems, internet-based instrumentation system or internet-based Virtual Laboratory (VL). However, in order to design and develop the I-bRO system, different development steps have to be carried out and different precautions and factors have to be considered.

One of the important ingredients in any control system is the Measurement and Test (M&T) instruments and control devices such as the sensors, transducers and the actuators. These elements are deployed throughout any instrumentation systems or over any fields to monitor and control the intended system performance. These elements come in different forms, varying from standalone and portable instruments to complex and fixed measurement systems and handle different applications. When the M&T instruments and the control devices are a component of a complete control system; the readings collected by them are transmitted to a central processing unit or the main control room. Recently, M&T instruments have evolved from analogue systems, measuring and controlling a modest number of plant parameters, to digital systems with a large number of input and output quantities [2]. Measurement and automation applications, especially in the industrial fields, are no longer restricted to a single computer, but it is often required to make measurements at locations physically separate from a monitoring station [2]. There is great trends these days in

integrating the computer with the field instrumentation system and network them to form a network-based M&T system [3]. The network allows the remote access to the field instruments and device. The fastest growing and most talked communication network is the internet [2]. Intranets and the internet are assuming a greater role in the M&T field [4].

The future of the M&T instruments field will be shaped by their capacity to communicate with each other and to be controllable and monitoarable remotely whether through a wire or wireless communication techniques. Remote control system is a technology that is attracting increasing attention, particularly for commercial applications, because of its potential to reduce the complexity and cost of the M&T system in large networked applications. Remote access, monitoring and controlling of M&T instruments and control devices are emerging concepts that are currently being implemented in industrial applications [4]. The future trend in the M&T field instruments is toward the smart devices that have the potential to communicate with remote instruments and determine if the instrument is functioning properly [5]. Internet telemetry has been growing in popularity as a method of communicating with field M&T instruments remotely [6]. As a result, nowadays there are several commercial technologies using Transmission Control Protocol/Internet Protocol (TCP/IP) can provide advanced management features within M&T instruments. Web technologies can grant an easy access to different M&T instruments on the field from a standard web browser software which is included in most computer operating systems. The internet technology has great advantages when it is applied in different fields. The best of these is that, it saves human lives as it eliminates the need of a person to be present physically with the operated system since the communication between them can be carried out through the network. Beside that it reduces the total cost of the development since it facilitates the sharing of recourses between different users at different places connected to the same network.

The concept of networked M&T instruments is gaining foundation in several applications in industrial, research and development centres [4]. It is expected in the near future that, the M&T instruments users will not have to move from their offices to the field for the sake of collecting measurement data as that will be achievable remotely [7]. Beside that, the access to the M&T instruments will not be restricted to a single client as resources can be shared over the network as well [7]. Networking

different M&T instruments and control devices within any field reduces the complexity of the field central monitoring and control room and facilitates the communication of many field instruments and devices with the main control room. Beside that, with the networked instrumentation system, installation and maintenance costs have been reduced. Instead of each instrument and devices on the field being wired directly to the main control room in the plant, a multi-drop network using a common network cable such as the fieldbus, through which different M&T instruments from different vendors can be connected by the same bus, can be implemented [8]. This technique has reduced the instrumentation system complexity, the installation cost, the time and the man power required to maintain the work of the system within the field [8]. The big advantage of the networked instrumentation system is the degree of intelligence that have been added to the entire instrumentation system. That happens by enabling different M&T instruments and control devices within the filed to communicate and interact with each other and collaborate in making the decision for the system [9].

The traditional M&T instruments, whether they are in forms of shelf instruments or off-the-shelf instruments, are limited in their applications, performance and sizes. Most of these are not adaptable to different systems, as they have been designed to perform jobs predetermined by the vendors, and usually they do not have flexibility to be upgraded by the end users to perform different tasks. Moreover this type of instruments is space consuming, thus to handle instrumentation system of many parameters it is essential to have sufficient space to accommodate the large number of M&T instruments. One more technical block among what has been mentioned, related to the conventional instrumentation system is the capital investment to build such M&T system, which is high due to the cost of the individual physical instrument.

An alternative and a practical solution simultaneously for the traditional instruments is the use of software-based M&T instruments which are known by Virtual Instruments (VI). VIs can be defined as software-based instruments that are programmed to appear like familiar instrument panels with all functioning tools such as switches, sliders and indicators. VI has been also defined as a program in graphical programming language and models the appearance and function of a physical instrument [10]. This type of instruments emulates the appearance and the jobs of the physical instruments. They are built by the use of appropriate software

and a standard personal computer. In comparison with the traditional instruments, VI solutions have proven to be more powerful, easier to use, and extremely cost effective [10]. Recently, VI has started to play an important role in the signal analysis and signal measurements [11]. It has been extensively applied for the M&T purposes in different fields such as industries, laboratory experiments, medical applications, computerisation and performance analysis of machines and drives [12]. The biggest benefit with the VIs, as they are software based instruments, is that they offer the ability to customise the M&T instruments to specific applications of different users and bringing together a wide range of M&T functions into a single integrated system that can be easily expanded. Since the VI system is based on the computer software technology, it is far better than the traditional instrumentation systems for the data analysis, data presentation, database storage, and networking [13]. PC-based instruments enable the users to make use of the computer industry's ubiquitous communications and interfacing standards [14].

Because of the above mentioned advantages of the VIs besides some others; they will be used in the development of the I-bRO in this study to replace the physical M&T instruments and control devices.

1.1 The Research Goals and Contribution

The trend and focus of the control system designs is toward the networking attitude. The network can be created on a small scale as the intranet or over a large scale as the internet. The study in this report mainly focuses on the networked dynamic system over the Local Area Network (LAN) and it has been testified over the Wide Area Network (WAN) which is the internet. Incorporating the network in the control system design, allows having the system in a place and the person on duty in a remote place. Through the network link the communication between the two sides; the system and the remote operator, takes place as they were physically in the same location. The study has been conducted in a form of an on-line and real-time laboratory experiment of a dynamic system in which a user can carry out the experiment, perform real-time monitoring and controlling, and collect real and live data from the experiment through the network link as he was physically in the laboratory.

Networked the control system has some technical drawbacks related to the nature of the network for data transmission. The main goal of this study is to design and

develop a network-based control system and investigate the performance of the system on the network. To do so, this study has taken place through different stages as follows:

1. Stage 1. Interfacing the test-rig apparatus with a dedicated local computer.

2. Stage 2. Designing and developing the VI system to communicate with the system and replace the physical M&T instrument for the remote operation. This has been achieved by the use of the LabVIEW7 program. By this stage, a Computer-Based instrumentation and control System has been developed.

3. Stage 3. Uploading the developed system on the network (LAN & WAN) and studying the control system performance on the network.

The above listed stages have produced a highly reliable and flexible, real-time, on-line and web-based VIS by the use of the National Instruments LabVIEW real-time feature.

The study carried out and conducted in this research has the following main goals.

1. Designing, developing and demonstrating VIS, which can be used to control and monitor the performance of the dynamic system interfaced with a computer.

2. Studying and applying different techniques of computer-instruments interface.

3. Training the student of engineering discipline to design and develop an internet-based instrumentation and control system.

4. Developing a Virtual Laboratory (VL) of a common Electrical Engineering experiment for the use of both undergraduate and postgraduate students.

5. Studying the feasibility of utilising the new networking technology, such as the internet, for diverse applications of the on-line and real-time remote controlling and monitoring of a dynamic system.

6. Address and analyse the problems and limitations associated with the network in the I-bRO.

1.2 Thesis Outline

Each chapter in this report details a particular task of the entire work conducted under this research.

In chapter one, general introduction about the work that has been carried out under this study has been explained. That was followed by the research goals and the research contribution to the knowledge.

In chapter two the background details of the instrumentation system has been presented. Computer-instrument interface techniques have been also explained. Literature review of the VIs and some of its different applications have been presented. The concept of the VL has been explained.

Chapter three mainly concerns on the research test-rig development. Literature of the LabVIEW-based VIs have been detailed. A general methodology to create VI system to communicate with the research test-rig has been presented. Different VIs for the different parameters of the test-rig have been shown in this chapter.

Chapter four mainly focuses on the research goals and the test-rig implementation. Different tests used to verify the work of the I-bRO of the test-rig have been shown on this chapter. LabVIEW-based remote operation has been explained as well.

The key concept of chapter five is the I-bRO. As a result of the correct operation of the research test-rig, the I-bRO has been studied, problems related to that have been defined and addressed, and solutions have been suggested. Different scenarios of the I-bRO with random time-delays have been studied, simulated and analysed.

2 Background Details and Literature Review

2.1 Introduction

The majority of industrial organisations these days apply the computer-based M&T instruments to control and monitor the plant elements and devices in the field. This application ranges from standalone-computerised instrumentation systems to networked computerised instrumentation systems, such as the distributed control system. M&T instruments have passed through different progress stages till they are in the forms we have today [15]. In the beginning, instruments started as custom-designed single purpose instruments in which the instrument can handle only a specific single use of the customer need. The main character of this type is that they were fixed in one place or shelf-based and have a big size. The next generation was the general purpose and off-the-shelf instruments. In this design, different instruments were combined together in a single rack to handle different tasks individually while each instrument operates independently. Following to that, the analogue multi-purposes instruments have been introduced. After that, the digital and portable multi-purposes instruments have appeared. This type was incorporated with a signal processing capability leading to instruments with Digital Signal Processing (DSP) potential. The great advantage of this type of instruments when they are used in all applications is that, they offer greater measurement stability and improved resolution compared to analogue or traditional instruments [16]. The big revolution appeared with the invention of the Computer-Based Instrumentation System C-bIS. The great development with this type was the ability to coordinate cross-instruments operations and automatically sequence a complete test with a minimal operator intervention through a single computer [14]. C-bIS is becoming a common fashion for industrial applications because of the low-cost and the high performance of the computers [17]. Following to this type, the portable and small size on-card instrument have appeared. The obvious progress in this type was the ability to control the instrument and the data can flow over a fast bus channel [18]. This speeds up the M&T process and can provide the foundation for real-time testing of dynamic phenomena [18].

With all these types of M&T instruments, and despite the development and the progress they have passed through, there are some embedded technical limitations

accompany them such as the reliability (power- consumption), flexibility (re-use) and operability (multi-system operation) [18]. Beside that, and due to the fact, the physical instruments are costly and space consuming, to expand the tasks handled by this type of instruments requires buying another instrument and hardware which means extra cost and space.

To eliminate some of these limitations and technical barriers associated with the traditional M&T instruments, researchers, scientists and engineers have put great efforts till they came up with the new instrument generation which is the Virtual Instrument (VI). VIs are software-based instruments and do not exist physically. They imitate the appearance and the jobs of the real instrument. In this type of M&T instrument, the jobs performed by each instrument are defined by the software developer and thus they can be reconfigured to perform different jobs and handle different tasks. The most significant advantage of this type of instrument is the high speed, high performance, low initial cost, small space and the adaptability for different systems [19]. Moreover, the flexibility and reliability of the entire instrumentation system has been enhanced by the use of the VIs [19]. In addition to that, the capital investment of the entire VI system is much less than the conventional instrumentation system as the VI system needs only a personal computer, appropriate software and hardware such as sensors, transducers and data acquisition cards that is suitable to interfaces the system under M&T with the computer [20]. With the use of the VIs, the computer handles the acquisition of measurement data from different sensors and transducers with high sampling rate and high processing speed [21]. In addition to that, the VIs make use of the provided computer features such as the memory, the signal processing and analyzing beside the available simulation tools. In that essence, the measurement data can be saved for the future reference and off-line needs, analyses them, presents the acquired data in the required format and use the analysed results to perform control actions on the system if required.

2.2   Computer-based Instrumentation System (C-bIS)

C-bISs can be defined as the instruments that are interfaced and consequently controlled by a standard or advance computer through suitable software and hardware. The wide variety, high performance, and reasonable cost of both commercial M&T hardware and software make this type of instruments as an attractive choice for instrumentation system[17]. Recently, it is hard for any designer and developer to design M&T instruments or control devices without including an internal or at least readily available intelligence which takes the form of a standard computer [14]. In the C-bISs, user communicates with instruments, collects data, analyses and presents the measurement data in a better format than an individual instrument can do [14]. Moreover, by the use of the computer features, additional measurements and analysis can be performed out of the data collected from a simple stand alone instrument. Beside that, the C-bIS performs variety of measurements and permit high speed execution of tests through concurrent operation of individual M&T instruments [22]. The recently used C-bISs provide a permanent interconnection of groups of individual instruments through a common backplane wiring, which permits the instruments to be programmed for performing diverse aspects [22]. The most dominant feature of the C-bISs is the processing speed and versatility as the computer handles the data acquisition from different M&T instruments, saves the data, processes and displays it [21].

The incorporation of the computer with the instrumentation system begans as a way to enable the display of the measurement data on a VI panel on the computer, allow the creation of a simulated physical instrument and providing the capability to control physical components [23]. The first time PC-based data acquisition card introduced in the market was for eight-bits PC from LabMaster and that happened after six weeks from the introduction of the IBM personal computer in 1981 [15]. Since then, there are several computer-based data acquisition system have been developed with various combination of hardware and software [24]. The idea behind the development of a PC-based spectrum analyser suitable for use in undergraduate laboratories has been presented [24]. An undergraduate research project that involved the interface of a Hewlet Packard (HP) digital oscilloscope to an IBM computer using National Instruments general purpose interface board has been also presented [24]. From students prospective, the C-bIS field gives the student the required skills

in both fields; the computer and the instrumentation fields. It provides the computer science students the essential knowledge on sensors, actuators, and data acquisition tools while on the other hand it greatly improves the electrical engineering students with the computer programming skills [25].

The simple C-bIS consists of the following components [26]:

1. Host computer with standard interface tools.

2. Measurement software: it runs on the host computer under an operating system.

3. Data acquisition hardware: such as Digital to Analogue (D/A) or Analogue to Digital (A/D) converters. This could be in form of built-in or plug-in boards.

4. Communication hardware: these are the interfacing components which allow the host computer to communicate with system.

5. Field wiring: this connects the host computer to the field components in order to collect data.

6. Data sources: These include sensors and transducers which interface the physical world with the digital world in the computer.

7. Control devices: this includes actuators which receive signals from the host computer and implement them on the system.

These above listed components are illustrated all together in the diagram of Figure 2-1.
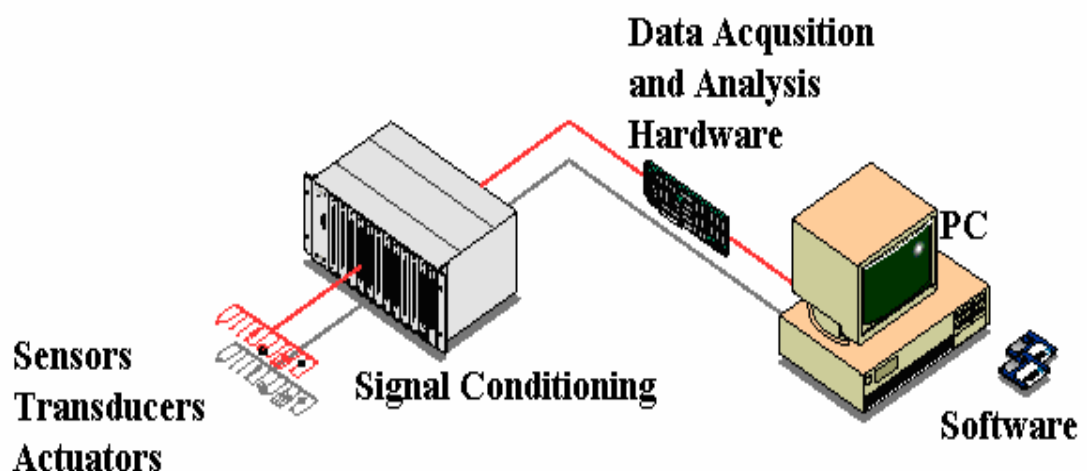
Figure 2-1 Typical PC-based DAQ system (adopted and modified) [27]

Modern M&T instruments are facilitated with different types of computer interface techniques [28]. This facility has enhanced the development of the C-bIS. Over the last three decades, data acquisition system has been the integral part of monitoring in any processing industry [29]. Because of the widespread use of the C-bIS, data acquisitions became more compact, versatile and cheaper [29]. There are several instruments and devices have been already interfaced with the computer such as the digital oscilloscope via the GPIB [30] and the digital multimeter [31]

Computers interchange data with external devices and instruments in form of digital electrical signals. However the signals generated from the physical world are in an analogue form. In order to process and analyse the analogue signals by computers, they have to be converted to the digital form through an Analogue to Digital Converter (ADC). Likewise if the signals generated by the computer are required for analogue applications, they have to be converted from digital to analogue form through a Digital to Analogue Converter (DAC).

2.3 Computer-Instrument Control & Interface

Computers, for it to be able to communicate and interchange data with external instruments or devices, they have to be interfaced together through one of the provided interfacing techniques. Interface standards techniques have been designed to permit instruments from different manufactures to be interfaced with a standard computer in the same way [32]. There are several ways of computer-instrument interface techniques such as the serial RS232, General Purpose Interface Bus (GBIP), the Standard Parallel Port (SPP), Ethernet, VXIBUS, Data Acquisition Card (DAQ) and the Universal Serial Bus (USB)…etc. It is common in each modern standard personal computer to have the serial, parallel and the USB ports for the external devices connection. The majority of modern M&T instruments and devices have the computer interfacing facility.

The M&T instruments used in this study are NANOVIP Plus, Load Cell, Data Acquisition Card (DAC) and the control box. All these M&T instruments are supported with the computer interface facilities. They have been interfaced with the local computer through the serial port, parallel port, DAQ and the USB. The computer interchanges data with the external instruments and devices through these techniques as follows:

2.3.1 Serial Port

In this study, NANOVIP Plus instrument has been interfaced with the local computer via the serial RS-232. Serial communication based or RS-232 standard is the simplest way of using a computer in measurement applications and control of instruments [20]. It is the transmission technique wherein data is transmitted over a single data line [32]. The name of this transmission technique is drown from the fact that this port serialises data bits one after another [32]. The data is transmitted in a form of one character or bit at a time. The individual bit is tracked by knowing its position and duration in the serial bit stream [32]. The Least Significant Bit (LSB) is the last bit of the data which, by convention, is transmitted first while the Most Significant Bit (MSB) is the first bit of the data and it is the last bit to be transmitted [32]. This is clarified in Figure 2-2. The receiver reads the individual bits of the data as they arrive. Serial communication protocol defines the order of the bit and the waveform shape in both time and amplitude [33]. In this protocol of data

communication, all data bits are sent and held for a constant period of time [33]. This timing period is the frequency of data transmission rate in bits per second and it is the reciprocal of the baud rate which is [33].
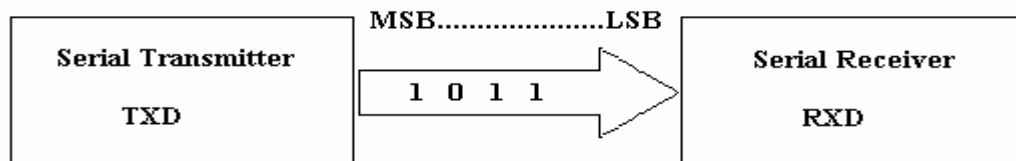
Figure 2-2 data transmission format in the serial port

A full-duplex communication, receiving and transmitting, between the computer and an external device or instrument can be executed over the serial transmission protocol [34]. For a successful serial communication, the serial protocol of the transmitter and receiver must match with each other. Before the communication is conducted, several parameters between the receiver and the transmitter have to be initialised [33]:

1. Port Address Baud Rate: signaling speed,
2. Number of data bit
3. Number of stop bits
4. Parity (0 for even, 1 for odd, or 2 for no parity).

The serial port connectors come into different forms and with different number of pins. In all forms, they have in common two data pins, five control pins and one ground pin [35]. Nonetheless, the serial protocol is limited in data transmission rate and distance (up to 115 Kbytes/sec, and 15 m) and it allows only one device to be connected to a computer per port [20].

2.3.2 Parallel Port (SPP)

In this study, this port has been used to interface and drive the load control box from the local computer. This port is commonly known as Standard Parallel Port (SPP). Through the SPP, computers transmit data to an external device or instrument in a bundle of eight-bits of data at a time [32]. These eight-bits are transmitted parallel to each other as it shown in Figure 2-3. Since the number of data bits that are transmitted in this method is eight, the SPP is faster than the serial port interface where only one bit is transferred for the same amount of data and with the same period of time. The SPP has the potential of transmitting 50-100 kilobytes of data per

second [36]. The SPP cable is composed of 4 control lines, 5 status lines and 8 data lines [37].
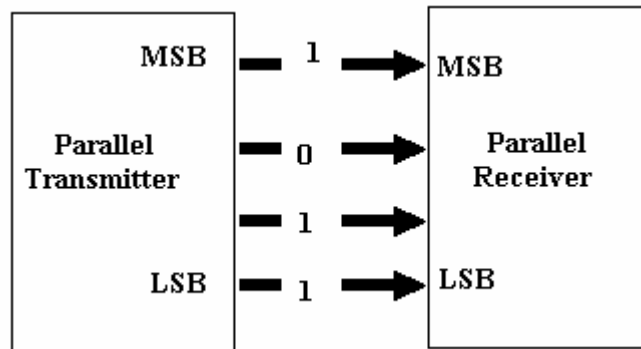
Figure 2-3 data transmission format in the parallel port

2.3.3 Universal Serial Bus (USB)

USB has been used in this study to interface the digital load cell instrument with the local computer. The USB relatively is a new way of interfacing external instruments and devices with the PC. Most new computers have one to four USB ports, in addition to the serial or SPP ports. Many of modern portable instruments and devices are moving towards the USB interfacing technique with the computers. The USB provides a versatile, flexible method of connecting a wide range of low and medium-speed peripherals to a computer at relatively low cost [38]. The USB interface is much easier in installation than the serial and the SPP as it has the plug-and-play configuration [38]. It is much faster than the serial or the SPP [39].

The good feature about the USB is its potential to supply power for the portable M&T instruments. This feature reduces the weight, the cost and the sizes of the instruments and devices as they don't have to be battery-powered or plugged into the wall [40]. USB cable comprises four wires: two carry signal data and two supply voltage to the attached device [41]. USB bus can operate at two different speeds; depending on the attached device as the device itself tells the bus what its speed is through the voltage cables [41]. In 2000, USB 2.0 specifications have been released and it has the potential of transmitting 480 megabits of data per second [41].

2.3.4 Data Acquisition Card (DAQ)

DAQ card has been utilised in this study to interface the Induction Motor (IM) shaft with the local computer in order to measure the rotational speed. The DAQ is

connected to the IM shaft through the NI BNC-2110 kit. DAQ is a device that is used to acquire and convert physical signals generated in the real measurement world such as voltage and current into digital format and transmit them to the computer. At least over the last three decades, DAQ system has been the integral part in the monitoring of any industrial process [29]. In many applications, DAQ is used as plug-in devices to collect the measurement data and transfer it directly to the computer memory [27]. The software controls the DAQ system by acquiring the raw data, analysing and presenting the results [42].

2.4 Internet-based Instrumentation System (I-bIS)

2.4.1 Introduction

The continuous development and progress in the computer field and networking technology has enhanced the use of the existing computer features in the field of the M&T instruments, which in turn has enhanced the collaboration between geographical distributed research and development centers [43]. The network facilitates the possibility of having the M&T instruments in one place while a person interacts with them remotely from another place. The M&T instruments and the resources required for data processing are increasingly distributed in space, time, or scale [44]. The classical circumstance for the distributed instrumentation system is the distributed system in space, where different M&T instruments are located at one place; the main control rooms are located at others, and the measurement data processing, analysing and storage yet at others [44]. Another circumstance of the distributed instrumentation system is when the direct control or monitoring of the M&T instruments is not possible such as in hazardous areas [44]. Many microscopic experiment environments fall under this category. The modern instrumentation system environment is characterised by continuos increasing quantities and rates of data together with the remote interaction of the humans and hardware.

Networking has been introduced successfully in the instrumentation field to interconnect different instruments and data processing sites into a Distributed Measurement System (DMS) [20]. The future trend in the M&T field instruments is toward the use of the smart devices that have the potential to communicate with a remote M&T instruments and determine if they are functioning properly [5]. The great advantage of networking instruments is the ability to share resources between different users especially in the research centers and educational institutes. Moreover, users will be able to communicate with the field M&T instrument, collect real-time measurement data and control the instrument remotely over the network link. With the distributed measurement system and remote measurements, measurement programs execution and measurement data publishing can be taken with an ease over the internet [20].

The communication network takes two forms; large scale or the internet (WAN) and small scale or the intranet (LAN). The use of the internet as a media for data

interchange provides cost-effective, flexible and easy to access distributed systems that are not limited to any geographical boundaries [45]. As the WAN is built on numbers of individual LAN, through the combination of the WAN and the LAN, users can get an access to any instrument or device connected to any of these two networks [3]. With the networked measurement system, the collected measurement data can be shared not only by different applications of the same acquisition computer but also by other computers connected to the network [46]. I-bIS is a developed form of the currently used C-bIS as it adds an advance level to the C-bIS by incorporating the internet in the design and globalises the communication link between the field M&T instruments with the user. I-bIS is flexible, cost effective, powerful and it has increased the entire system productivity [47].

From the design prospective, there are two different methods to design the I-bISs [48]. The first design is based on interfacing the instrumentation system apparatus with a local computer, which acts as an instrumentation server, and that computer, in turn, can get an access to the internet. The second design is based on using instruments that have built-in internet serving facility as there are new ranges of controllers and instruments that can serve the web pages. In the second design, the instrumentation server (local computer) can be eliminated from the design [48]. The two designs are illustrated in Figure 2-4 A & B.
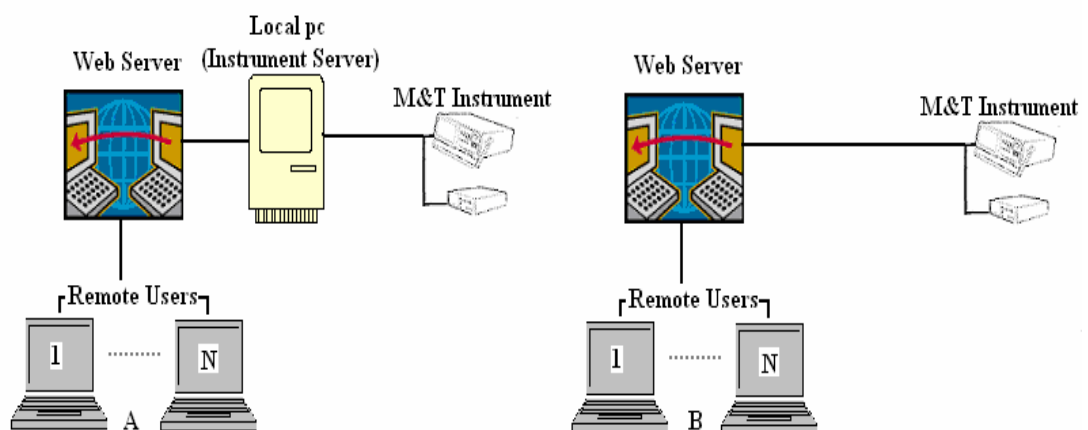
Figure 2-4 the tow different design methods for internet based instrumentation system

2.4.2 I-bIS Literature Review

I-bIS have attracted the attention of many researchers and significant works have been made so far. Literature has shown much works have been conducted to

incorporate the World Wide Web (WWW) into many aspects of research, education, medicine and industrial instruments and devices. Current trends are toward developing the internet-based instruments and devices of various types.

The idea of internet-based M&T instruments has been already successfully used [48]. Recently, there are quite few companies have put efforts to produce the I-bIS as control devices [49]. Most industry experts agree that the combination of the IP networks and the public internet will soon play a vital role in virtually all Supervisory Control And Data Acquisition (SCADA) systems [50]. Networking measurement system has been studied and a new Java-based software environment for Distributed Measuring Systems (DMS) design has been described [51]. The concept of utilising the web-based instrumentation tools has been proposed [52]. In that proposal, the authors have suggested a new concept due to the geographical distribution nature of the M&T instruments. The principle of this proposal is to have M&T system of two sides. On one side there is an instrumentation pool consists of groups of M&T instruments distributed anywhere in the world, connected via standard interface bus to a workstation which in turn is connected to the internet. The other side of the system is a computer front panel where the details of different M&T instruments are presented on the web page. The link between the two units permits a specified class of users to access the instrumentation pool and to perform measurements tasks [52].

One of the first devices that has appeared over the internet was the Cambridge Coffeepot at Cambridge University in 1980 [53]. Nowadays some researchers try to bring different types of M&T instruments and devices into the internet server [54], [55], [56], [57], [58]. Several researchers and developers have discussed the I-bIS [3], [59] ,[60] and developing a general methodology to the GPIB-based instruments through the internet has been discussed [48]. Researchers at Arizona State University have succeeded in bringing live data of the Scanning Probe Microscope (SPM) on the web [61]. A distributed digital measurement architecture which embodies various elements of the instrumentation system to meet the industrial needs has been already proposed [2]. This proposal has been tested onto two applications; the monitoring of power quality in an electrical distribution network and the management of a water distribution system. The architecture of that proposal was arranged on three hierarchical communication levels; the fieldbus, the intranet (LAN) and the internet (WAN). Truly interactive bi-directional communication involving feedback and

control of instrument through the web has been used [62]. A distributed measurement architecture for industrial applications, which uses a VXIbus system as the data server has been proposed [2].

The design and implementation of a web-based data acquisition system which allows regular updates of telemetry data for multi-user from remote station site has been presented [29]. An internet-based and real-time remote patient monitoring service, bedside monitoring server and patient locater server that allows physicians to monitor patients remotely through a standard web browser has been developed [63]. The development of a practical training system for graduates that allows instruments to be monitored and controlled over the internet has been presented [54]. The system takes the form of an on-line experiment in which students situated at remote locations can control and obtain real-time measurements and experimental data from instruments connected to a host computer (server) by means of the GPIB-cable interface.

This literature strongly indicates the future trend on the instrumentation system is toward networking different instruments in different locations for them to be used from anywhere on the globe. The future of the scientific, research, medical, industrial and similar instruments and devices will be real-time and on-line instrumentation systems that are connected together via a single network. This field will be decentralised and a user from anywhere and at any time will be able to communicate and interchange data with systems in remote locations through a simple and standard computer connected to the internet and has a web browser.

2.5 Virtual Instruments (VI)

2.5.1 Introduction

The nature of the traditional M&T instruments are application specific systems as the hardware and software components that have been used to develop them are fixed. Due to that, the manufacturers define the instrument functions and applications during the designing and manufacturing process. The feature of these instruments is complex and consequently they become expensive and difficult to manage. Most of the physical instruments and devices have the potential of conducting individual tasks but they do not have the flexibility required to perform multiple tasks simultaneously [64]. Beside that, to conduct extra jobs means more instruments or equipment and this addition leads to extra cost and more space. On the other hand, the continuous development and progress in the M&T instruments and the computer-programming fields has led to the invention of the VI. VIs can be defined as software-based instruments that are programmed to look like the physical instrument panels, including switches, sliders and indicators. It has been also defined as an integration of sensors by a computer equipped with a specific data acquisition hardware and software to permit measurement data acquisition, processing and display [20]. The term virtual refers to the fact that the display and processing of information is controlled by software and can easily be reconfigured to cope with various applications [65]. The main philosophy behind the invention of the VIs is to develop a powerful, yet flexible and cost effective instrumentation system that is using a standard personal computer and affordable software. The current developments trend in the M&T field is toward the VI and integrate it with the internet [66]. The instrumentation industry is moving steadily and continuously toward the VI although it is not expected for the VI to eliminate the need for the traditional instruments in the near future [24]. VIs or software-based instruments are different from the physical instruments as their tasks and applications are defined by the software programmer or the end users. Therefore, depending on the programmer experience on the software used for the development of the VIs, multitask instruments without the need for extra equipment or extra spaces to accommodate the expansion of the measurement system can be developed. Because of these reasons and others, software-based instrument are likely to be used in research or process

fields. It has been noticed, by utilising the VIs, companies easily modify testing, measurement, and control procedures without the need for purchasing additional equipment [67]. Yet and despite the successful applications and implementations of the VI in the fields of electronics, telecommunications, semiconductor, and automotive industries which are previously considered inaccessible for C-bIS, vendors and users have realised that VIs are not expected to totally replace the physical instruments or eliminate the need of them [4].

The future M&T instruments are shaped by many factors such as; the continuous development of dedicated acquisition technology and data analysis, intuitive and versatile user interfaces, advanced computer performance, free software architecture and adaptability with a third party [7]. VI meets these criteria and that makes the VI as the right choice to be applied in the instrumentation field. The three basic functions of a real physical instrument are data producing or data acquisition, data processing or data analysis and data presentation or data display. These functions can be implemented with the VIs easily and with cost-effective way as a standard personal computer could handle all these different tasks [13]. Lately, many companies continue to invest in developing the VI as it has reduced significantly the cost of the instrument for the M&T applications [67].

The VI field is a knowledge area that integrates several others fields such as the instrumentation system, the concurrent programming, Graphical User Interface (GUI), the real-time system, Object Oriented Program (OOP) and Object Oriented Technology (OOT) [68]. It is a result of the combination of a general purpose computer with a generic data acquisition system in order to emulate several traditional M&T instruments [69]. VIs are applied where the measurement process is a combination of different data and has to be mathematically manipulated or transmitted or recorded or displayed [70]. The concept of the VI can be extended to the virtual controller to implement multiple control strategies [70]. VIs have proved their ability to give the best results when solving complex measurement and control tasks [70]. With a proper hardware, VIs can be used for remote data acquisition, analysis design and distributed control [47].

There are two ideas to be considered when the VI is discussed [71]. The first idea is the possibility of controlling instrumentation system by means of a computer, and therefore giving the user a friendly and easier to use graphical interface. The second idea is to present software algorithms that simulate the physical instruments

behaviour as VIs.

Recently there are many programs have been used to design and analyse different instrumentation systems. Some of these programs are text-based where users have to write number of lines to analyse and design M&T systems. Beside that, these programs are not users friendly and take long development time. By the invention of the OOP, there are several programs that are interactive and user friendly have been introduced [72]. Some of the programs that have been used for developing the VI are LabVIEW, LookOut, BridgeVIEW and LabWindows/CVI [73] or PSPICE and MatLab [72]. In order for the VI to replace the physical instruments, the designers or the developers should consider both sides of the physical instruments; the hardware and the software that perform the data acquisition and control, the data processing and the data presentation in deferent ways to take maximum advantage of the PC [20]. This has to be fulfilled in order for successful replacement of the physical by the VI. The basic structure of VI includes the followings [20]:

1. A computer and a display.
2. The VI software.
3. A bus structure (that connects the computer with the instrument hardware).
4. Instrument hardware (sensor, transducer and conditioning circuit)

The main features of the VI system are [70], [73], [74] :

1. Ability to integrate multiple actuators, transducers and sensors
2. Flexibility in defining the measurement and control target
3. The ability to integrate different sub-systems
4. The capacity of performing multiple tasks
5. Operability: to be interfaced with other systems.
6. The virtual instrumentation system is an integrated platform in which vendor provides the hardware and the software while users define the function of the system.

In the internet environment, there are four categories in which VI can be applied. These being: remote monitoring, collaboration, distributed computing, and continuous remote control systems [75]. These can be explained as follows [76]:

Remote Monitoring and controlling: VIs facilitate the monitoring and controlling, through a communication network, of a system located in a remote location. However, remote control applications over large-scale network require more thought

in design and implementation in comparison to the remote monitoring as the remote control is influenced by many factors that have been discussed in the chapter five of this report.

Collaboration: incorporating the network with the VI facilitates the share of resources among different clients at different geographical locations connected to the same network. This feature has great advantages in the education field in which different academic institutes can share laboratory experiments.

Distributed computing: signals processing and computing are distributed over different processors. Different jobs can be divided among different processors on the network and thus each processor runs in a more efficient manner.

2.5.2 VI Literature Review

VIs have been extensively studied and applied by different researcher for training, teaching or analysing purposes [65], [77, 78], [79], [80], [81], [82], [83]. The method of developing a VI Platform (VIP) that use the concept of the Autonomous Decentralised Systems (ADS) technique has been described [73]. VIP provides an integrated frame, in which all software, hardware and algorithm are added as modules and with the use of the VIP, the user can construct a measurement system easily [73]. Moreover, the user can add or remove module for extending or developing the existing system. The development of a low cost computer-based virtual digital oscilloscope has been presented [24]. The authors have designed VI of the digital oscilloscopes as it can be used for analysis of both analogue and digital circuits with high accuracy. The VI that can be used to automate and test the electric drive system has been successfully applied [79]. The authors have concluded that with the use of the VI, the performance analysis of electric drive became easily [79]. Moreover, the author has claimed that "this particular application of VI leads to internet or intranet monitoring of the drive systems in the industrial environment and the laboratory for teaching and training purposes" [79]. VI for power analyser which includes harmonic analyser and instantaneous power measurement has been developed [80]. A complex VI system for measurements of mechanical and thermal parameters of an ancient masonry bell tower has been described [74]. The author has attributed his choice of the VI for its features which allow the most complete chances to have all requirements satisfied without limitations deriving from each instrument characteristics [74]. The implementation of VI-based on reconfigurable data

acquisition systems has been proposed [69]. The whole system is characterised by its versatility because software and hardware modules change dynamically according to the application requirements. According to the authors, VIs provide a link between Computer Aided Learning (CAL) tools and the external systems used in practical experiments [69]. An internet-based virtual wire applications that uses VIs have been presented [75]. In that study, the system gathers data from remote signal sources and publishes them via the internet in the real-time, while enabling the remote user to send control signals from the web browser to the server application [75]. An internet and VI-based SCADA system for industrial applications has been developed [84]. To achieve that, the developer started by developing general purpose VIs which will be used to communicate with RS232-based instrument, acquire measurements data, transmit and receive data both over the internet [84]. Internet-based VI that can be accessed through the internet, by any Java-enabled web browser, and allows users to perform both remote control and monitoring activities has been developed [76].

It is now clear that with the use of the VI, the way we look toward the M&T system has been simplified. Instead of using several stand-alone physical instruments for multiple measurement tasks and performing elementary analysis by hand, engineers and scientists now can quickly and cheaply create a system equipped with embedded analysis software and a single measurement device that has the potential to replace many stand-alone instruments.

2.6 Applications and Advantages of the VIs

2.6.1 Applications

There are different areas where the field of the VIs and the field of the networking technology can be used. The combination of these two fields has been intensively applied so far in medicine, industry and education or research fields. This research mainly focuses on the industrial application of the combination of the VI with the networking technology. However, other applications such as the medical applications or the educational applications will be addressed in this section. As it has been stated in an earlier stage of this report, this study is carried out in a form of an on-line laboratory experiment. In the next section, the internet-based application in the medicine and education are discussed. The internet applications in for the industrials monitoring and controlling purposed is postponed to chapter five of this report.

2.6.1.1 Telemedicine

Telemedicine or Tele-health can be defined as the process of providing a medical service remotely to a patient through one of the communication media such as the internet without the need for the physical presence of the patient. It has been also defined as the use of telecommunication to provide medical information and service between a patient and a doctor without either of them having to travel [85].

It is a natural use of the internet to be applied in the medical applications [64]. Telemedicine is an important field because it will facilitate the medical service for the remote places and areas that are without the medical specialist. It will help the developing countries because they will be able to contact with medical specialists around the world through the internet and by doing so, they will provide better care to their patients.

Recently, there have been a growing use of the internet in the telemedicine field, and in the mid-1990s an explosion have been witnessed with regard to the number of telemedicine related articles that have been published, and the projects that have been implemented [86]. There are some telemedicine systems have been proposed to be interfaced with the internet. Integrating the internet with the VI to develop telemedicine system has been already studied [64]. The combination of the computer resources and the instrumentation hardware with the software for data analysis,

communication and graphical user interface facilitates the development of the VI required for the medical application [64].

2.6.1.2 Virtual Laboratory (VL)

Courses in control system and instrumentation usually require an expensive hardware support, as the associated apparatus and equipment are normally costly. Implementing the idea of the VL will reduce dramatically such project costs as many users at different places can share the same resources. Apart from using the internet for the traditional applications such as reading the latest news of the world, chatting, making business… etc, academic organisations have made use of this technology to enhance the education process by developing virtual education systems. The www has offered a great opportunity to the academic organisations and research centres to develope VL based on the remote control of instrumentation system, as the use of M&T instruments through internet has been already used successfully [48].

Virtual education system are those systems that run through the internet environment in which the teaching materials are delivered to students remotely thus eliminating the need to attend and sit in classical classrooms. Likely to the virtual education system, experiments and classes run over the internet are called virtual experiments or VL. VL or Remote Accessible Laboratory (REAL), as some researchers call it [87], means a laboratory experiment can be conducted remotely without the need for the physical attendance in its real place or laboratory. In the VL paradigm, the experiment could be performed with its real apparatus or the apparatus could be simulated by a computer software simulator. With the VL techniques, users can plan and conduct the laboratory experiments, collect the measurement data and study the results as if they were physically present in the experiment place.

There are strong factors that impose the practice of the VL method in education such as the disability with some students that holds them from performing the laboratory experiments. Beside that the cost accompanies for the development or upgrade of experiments, holds back the developer and acts as a technical road block for the teaching development. VL facilities will allow students to access sophisticated M&T equipments and allow them to carry out real measurements on them which without it may will not be able to realise these experiments [48]. VL has the structure shown in Figure 2-5. From the structure in this figure, it is clear the experiment apparatus are located in a place while different users sit in another place

and through the network path the interaction between the two sides takes place.
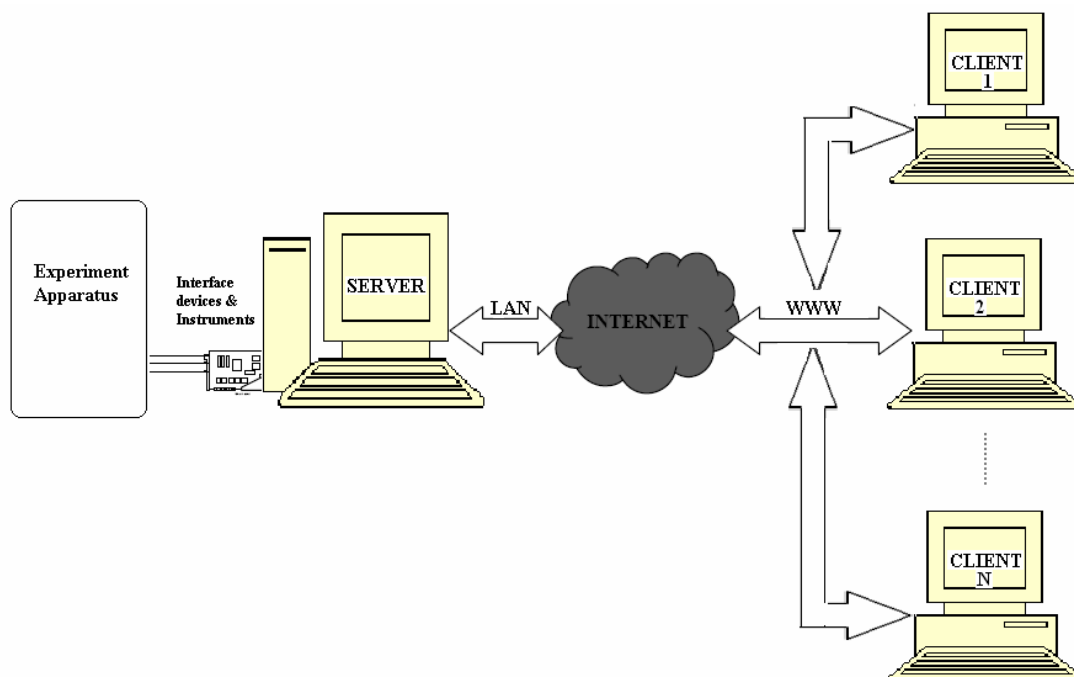
Figure 2-5 VL Structure

2.6.1.3 Virtual Laboratory Literature Review

Literature has shown several developments of the VLs in different fields. However, most of these developments do not involve the use of the real instruments but instead they use a software simulator [54]. This kind of tools do not make the same benefits in comparison with the real equipment experimentation [48]. "Simulators are not expected to replace the real instruments but can be a powerful auxiliary didactic tool for the students in order to help them to become acquainted with the instrument and its controls and operations both in the class and remotely" [77].

The remarkable progresses in the internet and web technology tools developed in 1990s have made it possible to remotely access an experimental laboratory [88]. Since then, there have been continuous efforts in developing web-based education environment at many academic institutions around the world [59]. In the future, it is expected the internet will be the teaching media for the distance learning system [89]. Most of the universities these days receive the interent service through the broadband method and this makes it possible to establish a real-time and on-line VLs [90]. Researchers at the University of Tennessee have developed the Controls Lab On-line which allows users to conduct remotely a VL [56]. The idea of global

laboratory environment in a way the apparatus of one experiment are distributed geographically in different places has been discussed [57]. It was concluded if the network parameters such as transmission speed, bandwidth or bit transmission rate are slow, the data would be broken and distorted and practice of the VLs would be impossible [57]. An intelligent universal VL which targets individuals who have disability on their upper bodies to perform laboratory experiments has been studied [91]. A real-time remotely accessible control laboratory for control engineering has been developed and demonstrated [56]. In that development, students or users can access the laboratory experiment at any time and from anywhere using a standard web browser to control and monitor the experiment in the real-time. At the Oregon State University, researchers have developed a system known as Second Best to Being There (SBBT) [56]. It allows users to receive both audio and video live images from the laboratory. The objective, strategy and implementation details of a new undergraduate course of internet-based instrumentation and Control has been presented [25]. This course, as per the authors, is offered to senior-level undergraduate engineering students who are interested in sensing, instrumentation, control and web programming and keen to learn more about the integration of these technologies for solving real-world engineering problems. Furthermore, it will be also offered to talented high school seniors as a vehicle to attract them to engineering disciplines. Implementation of a web-based VL concerning a Coupled Tank Apparatus using the Transmission Control Protocol (TCP) for communication has been reported [92]. A remote-access control VL for a dc motor control module that allows users to perform control experiments through internet has been presented [59].

A remote laboratory called VLAB of an oscilloscope experiment for first year undergraduate engineering students in the faculty of Engineering at the National University of Singapore in 1999 has been developed and launched [93]. In that development, real-time video images of the actual oscilloscope display has been used. One main feature of this development, according to the author, the use of the mouse to turn the control buttons and knobs of the instruments has been implemented so that a more realistic feel of the instruments is provided to the remote users. An interactive on-line VL for remote education called Automated Internet Measurement Laboratory (AIM-Lab) which utilises both the internet and the www has been established at Rensselaer Polytechnic Institute [94]. The AIM-Lab system, which is

based on the client/server architecture, uses non of the commercial software packages that are used to build any VL [94]. This feature, according to the authors, makes the system independent of the process of commercial software development.

It is feasible from the above literature that researchers have focused on the development of remote control VLs with different approaches. The advantages of using the VI to develop the VLs is that, a VI is easily reconfigured to create an individual laboratory experience based on each students skill and knowledge while maintaining the fundamentals of the experiment [67]. The classical method of conducting laboratory experiment, by the use of the physical M&T instruments, is accompanied by some difficulties such as the post experiment calculations of the measurement data, the relationship between the experiment different parameters are found after the experiment, students sometime cannot observe on the real-time the effect on the system parameters due to any changes on the other experimental parameters. With the use of VIs, students can keep track and notice in the real-time the effects of the experimental variables alongside while the experiment is running. As an example from this study, the users can immediately notice the effect of attaching and detaching the load to the test-rig parameters, the effect of that on the entire system performance, changing the supply voltage, or changing the connection of the system. Beside that, there are some other advantages of real-time and internet-based laboratory such as the teacher can assign laboratory exercises as homework and the laboratory can be run at any time from anywhere [90]. In addition to that, internet-based VLs have the potential of overcoming geographical and temporal restrictions and thus the laboratory resources can be efficiently utilised [95].

Generally, the VL idea has provided a valuable opportunity to the academic institutes and research centres, in particular, to share and use efficiently the available resources with each other thus reducing the research and development cost. With the VL technique, student from different fields and in anywhere of the world will be able to conduct, through the internet, laboratory experiment that are not provided by their education provider.

2.6.2 Advantages of the VIs

Researchers have mentioned different advantages for the VIs in different applications. Some of these are [52], [77], [64], [96]:

1. Flexibility. Additional functions can be added to the instrumentation system without extra cost or more space. Furthermore, the functions of the instruments can be changed, modified or even cancelled as per the user need as that depends on the software developer.

2. Storage and Display feature. VI takes the advantage and the benefits from the latest technology incorporated into computers. Computer features added to the M&T instruments more degree of intelligence.As a result of that, VIs are much better than the traditional instruments in data storage or data presentation and these are achieved with low cost in the VI.

3. VIs offer very user-friendly and comprehensive user-interface as their front panel is the computer screen.

4. VI enhances the distance learning scheme as it allows students to limit the costs for continuous training both by providing in-house educational facilities that can be used with a flexible and adaptable schedule and by reducing the time spent in an educational laboratory.

5. VI enhances the collaboration between the educational and research centres by sharing resources.

6. VI offers flexibility in measurement and the development of laboratory procedures as well as emulate industry standard practices.

7. VI has started to play an important role in the signal analysis and signal measurements, including various instruments for time frequency analysis.

8. VI takes the advantage of the networking technique thus a large decentralised instrumentation system can be constructed. The access to remote instruments sites connected through a computer network becomes an interesting solution to limit training costs without constraining educational opportunities.

9. Internet-based VI enhances the communication between students from different countries to discuss same interest topic, which in turn enriches the student or user knowledge in that subject.

3 System Development

3.1 Introduction

In order to study the networked dynamic system and the effect of the network on the system performance, a case study of an on-line and real-time VL for a common Electrical Engineering experiment has been selected. The experimental dynamic system that has been selected is a 3-phase Induction Motor (IM) and mechanically coupled with a DC-Dynamometer which acts as a variable load for the IM. The experiment apparatus are located in one of the Electrical and Computer Engineering department laboratory at Curtin University, interfaced with a local computer located by the experiment test-rig. The test-rig has been firstly interfaced with the local computer to develop a computer-based system. With this design, the measurement data and the control commands have been both collected from the test-rig and sent back to the test-rig through the local computer. The system performance was monitored and results have been recorded in the real-time. Secondly, the test-rig was tested over the network in both forms; the LAN and the WAN. In both cases the system performance again was monitored and recorded. The philosophy of the second test was to investigate and study the effect of the network, as it is the media of data communication between the test-rig and the remote user, on the dynamic system performance.

To perform the tests of this study, different steps have been taken place in order to prepare the test-rig. These steps include the local computer and the test-rig interface, LabVIEW-based VIs design and developing the networked-based remote operation. In this system, remote users from anywhere and at anytime have succeeded to control and monitor the dynamic system parameters and obtain real-time measurements and experimental data from the system. The remote-based tests have been carried out mainly over the LAN of the university server. Due to the fact that, the LANs are different nodes on the main WAN, a remote user connected to the WAN server can access any node on of the LANs. Therefore, the Internet-based Remote Operation I-bRO has been also performed from outside the university server. The difference in the system performance as a result of enlarging the network scale from the local area to the wide area has been noticed and recorded.

The apparatus of this study test-rig are as follows:

1. A 3-phase squirrel cage Induction Motor (IM), 440 V, 4.6 A, 50 HZ, 2.2 K.W and rotates at a rated speed of 1420 RPM.

2. A DC-Dynamometer, 220 V, 12 A, 2.24 K.W and rotates at a rated speed of 1200 RPM. This acts as a variable load to the system. However, the load provided by the DC-Dynamometer has been replaced by an external load bank.

3. A NANOVIP Plus instrument from elcontrol energy net company. This M&T instrument measures the voltage, current, power and the power factor from the IM side.

4. A digital and serial port supported digital load cell from Interface Company for the measurement of the system developed torque.

5. A Personal computer (Intel-P4, 2.6 GHZ, 530 MB-RAM, MS Windows-2000). A LabVIEW7 program has been installed on this computer. This PC is equipped with a LAN card to be connected to the LAN which in turn grants the communication path to the WAN.

6. A DAQ card, which is supported with a BNC-2110 from National Instrument (NI), interfaces the IM shaft with the local computer to measure the IM rotational speed.

7. An in-house designed and developed load control box to interface and control the system load from the local computer.

8. Two high voltage contactors replacing the System Isolator Switch (SIS) and the Load Isolator Switch (LIS).

The setup structure of the system is shown in Figure 3-1 and the data flow diagram of the system operation is shown in Figure 3-2.
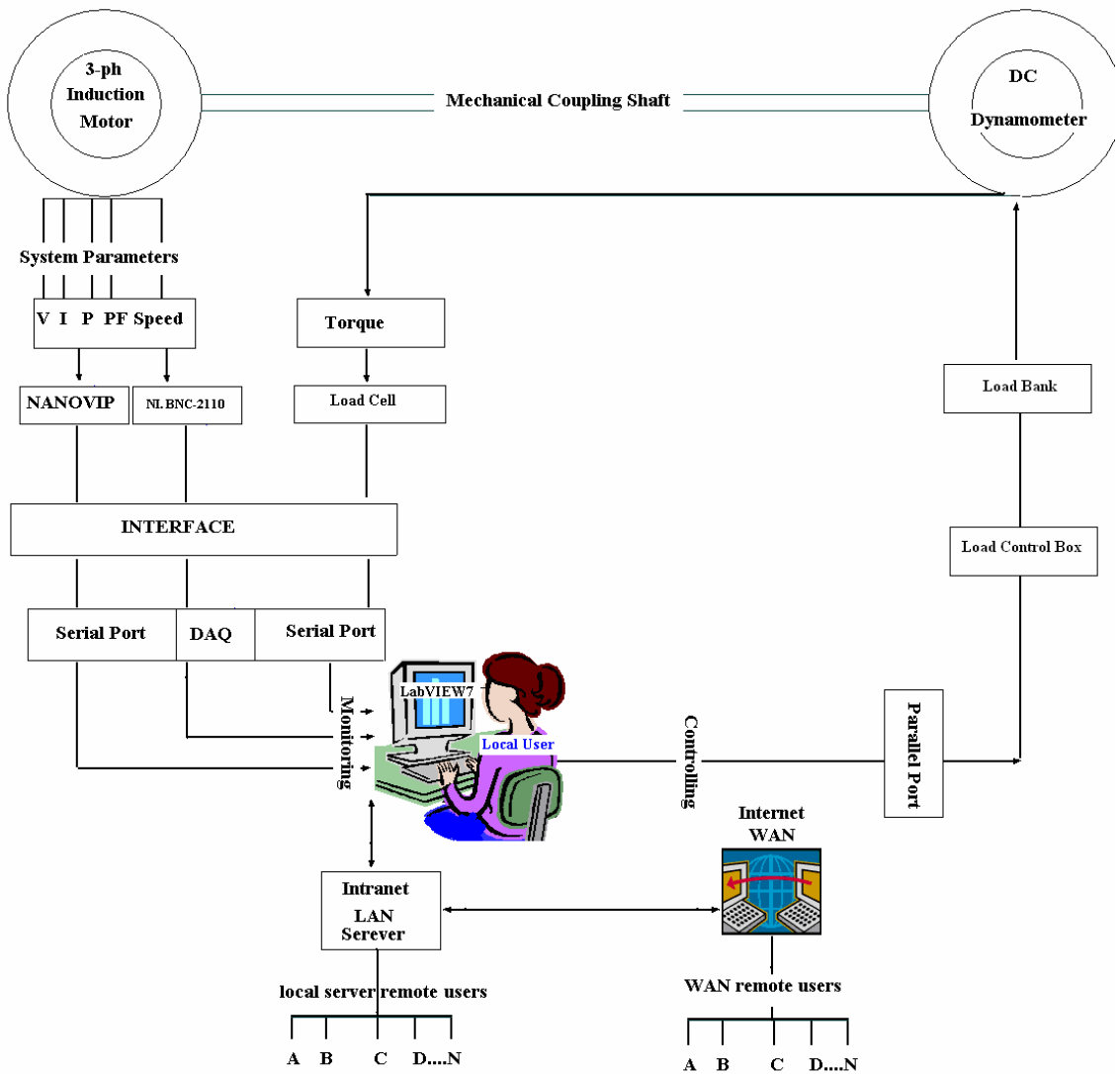
Figure 3-1 Structural design of the laboratory experiment
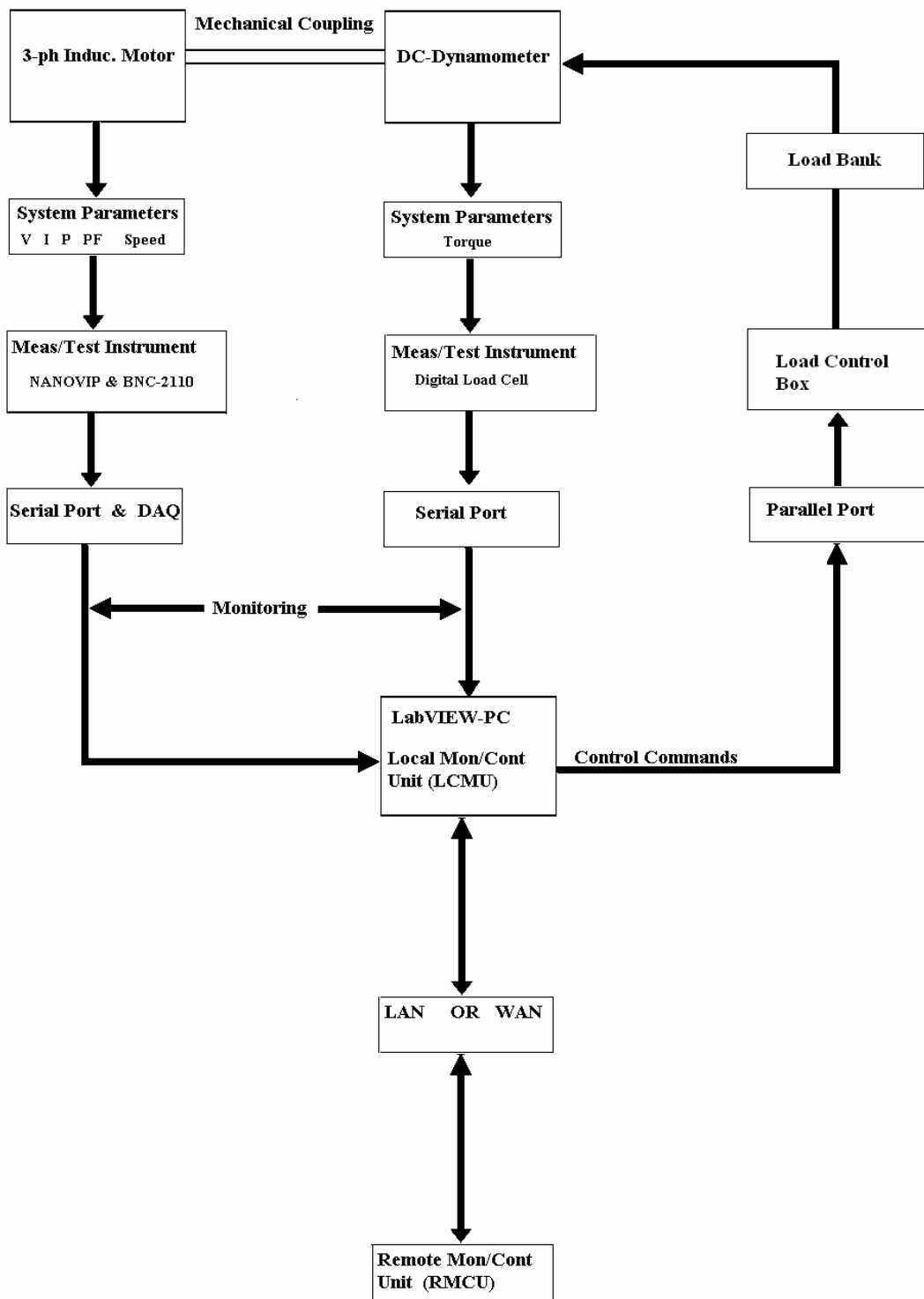
Figure 3-2 system data flow diagram
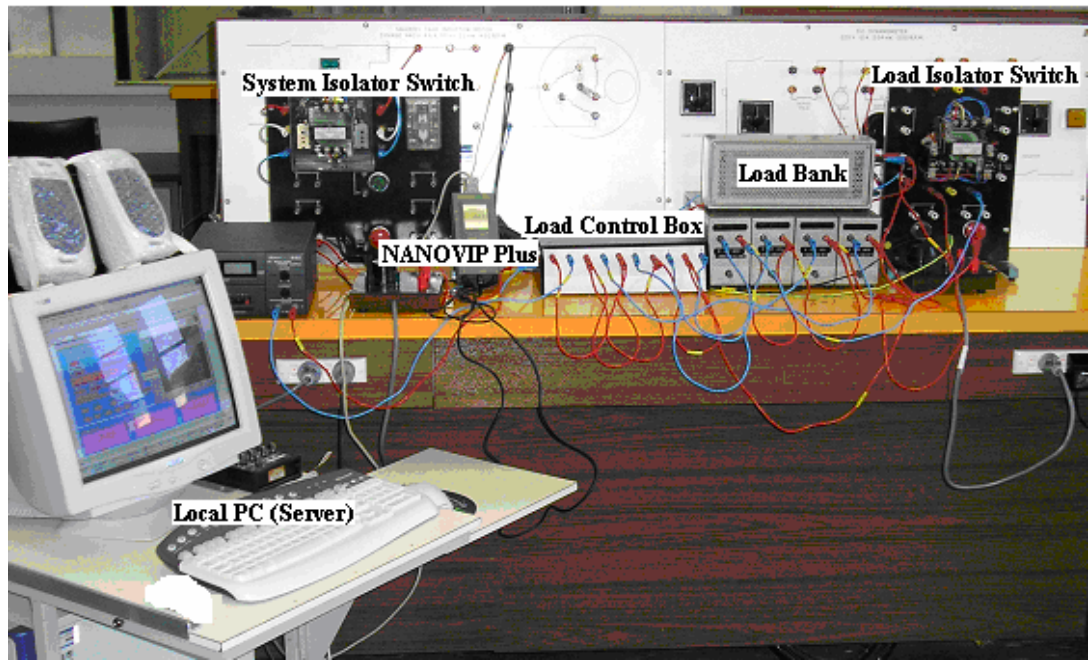
Figure 3-3 the connection of the test-rig apparatus

The M&T instruments used in this study have been replaced by LabVIEW-based VIs. With suitable interfacing methods, the developed VIs communicate and interchange data with the test-rig instruments and devices. The test-rig apparatus have been interfaced with the local computer through the serial port, SPP, USB and DAQ card. The local computer is directly connected to the LAN through the provided network card.

It is important to highlight that the VIs that have been designed and developed in this study are of real physical M&T instruments, and the data collected, processed, analysed and presented is a real world data and no simulation was involved. The system has been monitored and controlled locally via the local computer inside the laboratory and remotely through the LAN provided the remote user has an access to that computer through the LAN.

3.2 Computer-Instrument Communication

Computer communicates and controls any external instruments or devices by sending the control commands and data to the instrument through the mean of the interface. Different methods for computer-instrument interface have been explained in details in chapter two. Several computer packages have been developed to facilitate the computer-instruments communication and the package that has been used in this study to design and develop the VI system for the computer-instrument control and communication is the LabVIEW7 from National Instrument (NI). This program is considered to be the most powerful among the recently available computer packages for developing the VI and support the computer-instrument interface [21]. NI is considered to be one of the leading vendors in the area of VI. The engineers in NI develop, design and upgrade different types of VIs in both aspects software and the associated hardware.

3.2.1 LabVIEW

LabVIEW acronyms for Laboratory Virtual Instrument Engineering Workbench [33]. LabVIEW program developed by NI is a graphical programming language that uses icons instead of lines of text to create applications. LabVIEW is one of the graphic OOP language which has been developed to facilitate the hardware with the software communication [97]. In contrast to text-based programming languages, where instructions order determine the program execution, LabVIEW program uses dataflow technique, where the flow of data determines the program execution [98]. LabVIEW has become an important tool in the daily technologies and widely adopted throughout academia, industry and research laboratories as the standard for data acquisition, instrument control and analysis software [99]. It is the first programming language that can be used to develop M&T applications [15]. It has been reported that, LabVIEW has solutions for a number of engineering applications conveniently provided to the user by the NI Corporation [67]. According to this program developer and many researchers in data acquisition field, LabVIEW is revolutionising industrial measurement system and dramatically affecting traditional academic research and teaching [99]. This language is suitable for designing a man machine interface [84]. With LabVIEW program, designer builds a user interface with a set of tools and objects [100]. LabVIEW program can be applied for different

applications such as [47]:

1. Physical process simulation

2. Data acquisition and data processing: LabVIEW has built in library includes different algorithm such as signal generation, measurement, filters, windows, curve fitting, probability and statistic…etc

3. Instruments monitoring and control

4. VI development

LabVIEW programs are called VIs because their appearance and operation imitate the physical instruments such as oscilloscopes and multimeters. The VI that has been created by LabVIEW program are the easiest to be controlled and shared over the internet [47]. Every VI uses functions that manipulate input from the user interface or other sources and display that information or move it to other files or other computers. For acquiring data and controlling instruments, LabVIEW supports RS-232/422, IEEE488.2 (GPIB), and VXI, including VI Software Architecture (VISA) functions, as well as plug-in DAQ boards [101]. A VI is made up of the following three components [102]:

• **Front panel**: it is the user interface with the VI. The front panel is constructed with different elements such as controllers, indicators, meters, constants and graph plotter. These elements are the interactive input and output terminals of the VI. Controllers are knobs, push buttons, dials, and other input devices. Indicators are graphs, LEDs and other displays. Controllers simulate instruments input devices and supply data to the block diagram of the VI while indicators simulate instrument output devices and display data, which the block diagram acquires or generates, to the user.

• **Block diagram:** contains the graphical source code that defines the functionality of the VI.

• **Icon and connector:** identifies the VI so that user can use the VI in another VI. A VI within another VI is called a sub-VI, which corresponds to a subroutine in text-based programming languages. The sub-VIs can be interactively tested and used as icons to build more sophisticated VI.

LabVIEW models have been widely used for data acquisition and instrument control [103]. LabVIEW is extremely flexible and it is widely applied in simulation,

data acquisition & data processing [72]. In the field of data acquisition and measurement, LabVIEW is gaining its popularity as a graphical programming language [103]. Data acquisition, data analysis and data visualisation are three fundamental components involved in the acquisition and measurement process and these three criteria are all covered by the LabVIEW features [103]. Industrials, researchers and educational institutions have chosen this program for its high potential in advanced control and analysis solution [67]. In academia field, a LabVIEW-based laboratory makes researchers more productive and enhances the learning experience [99]. Instead of focusing on time consuming methods of gathering data, educators and students can focus on results and concepts. Especially in the academia, there are at least two ways in which LabVIEW can be used to make improvements [97]. One way is to update old instruments or build VIs to replace some physical instrument where they are lacking. The other way is to teach students about the OOPs and computer interfacing techniques. Beside that, it may be used to teach students about instrumentation.

For the above mentioned advantages of the LabVIEW beside others, LabVIEW has been selected as the development environment for this study.

3.2.2 LabVIEW and the Real-Time Operation

Real-time system or deterministic system has been defined as the system in which processes are executed within a specific time period, by which, the processes must be handled within a guaranteed period of time [104]. Real-time applications system does not always mean faster [105]. The amount of determinism in a system describes how reliably the system responds to events or performs operations within a given time limit [105]. Normally there is some variation in the execution time with all systems, but the variation in a real-time-based system is much smaller than the variation in a non real-time based system [105]. Generally, obtaining real-time measurements is a trivial task, as most data acquisition hardware components simulate dedicated clocks and buffers that allow for deterministic acquisition rates [104]. However, it is not easy to achieve a real-time response operation as it requires more advanced programming, thread management techniques and the use of a Real-Time Operating System (RTOS) [104]. The majority of the current dominant operating systems, including Microsoft Windows, have been designed as general-purpose operating systems and not real-time operating systems hence their exclusive

use would not be sufficient to produce a real-time system [104].

Beside the operating system being used, the real-time applications depend also on the communication protocol used for the communication between the client and the server. The common protocol used for the network communication is the TCP/IP or the UDP [105]. It has been found that, with the TCP/IP protocol there is no data lost throughout the communication link as the protocol is a confirmation based [106]. However, this protocol is not suitable for the real-time control as it has some time-delays. On the other hand, the UDP communication protocol is not a confirmation based and the order of arrival is not guaranteed either, yet it is preferred for the real-time applications [106]. From the LabVIEW prospective, both protocols; TCP and UDP can be used as the program includes TCP and UDP VIs and functions which can be used to create client or server VIs [105].

The latest version of LabVIEW program has introduced the real-time engine applications which can be used to view or control a VI from any web browser. This feature facilitates multiple accesses to the same VI from different users at different places [47]. LabVIEW real-time feature combines the availability of LabVIEW with the power of real-time systems so users can use graphical programming to create deterministic applications [102]. The LabVIEW real-time engine achieves deterministic performance by allowing critical operations to anticipate the execution of lower-priority tasks [102]. Anticipatory scheduling feature allows the processor to immediately stop executing the lower priority task when a higher priority tasks request time with the processor [102]. With the LabVIEW real-time feature, developers can use the standard LabVIEW function palette to perform data analysis, data storage, and network communication [107].

In this study, the LabVIEW7 real-time feature has been implemented to allow the remote access to the test-rig from multiple clients at different places. This task will be explained in details in chapter four.

3.2.3 Related Works with the LabVIEW Program

Many articles have been written on the applications of the LabVIEW in education, medicine and industrial setups. Many researchers have studied and applied this program to develop and design the VI system for different applications [94], [95], [108], [109], [110]. In 1998, a NI-Week that was run by the Worldwide Measurement and Automation conference has listed all papers related to the

LabVIEW program in the area of automation, control and instrumentation [99]. A data acquisition and control using LabVIEW for an innovative thermal conductivity apparatus has been described [99]. The LabVIEW-based VI has been used to monitor the parameters of a three-phase delta connected IM [79] and to control real instruments in an actual laboratory [111]. Applications of the LabVIEW in the teaching laboratories and how it can be used to control data flow between computer and external instruments or devices has been shown [97]. In the moon balance experiment, which is a famous control system experiment, LabVIEW-based VI has been used for interfacing and controlling purposes to implement the control mechanism in order to stabilise the system [75]. The main function of the LabVIEW in that experiment was the generation of a suitable PID control algorithm that is running in a local computer [75]. LabVIEW VIs have been used to communicate with DAQ cards in the senior design laboratory at Marquette University [67]. It has been also used in different universities to develop their laboratory courses for both undergraduate and graduate studies [67].

There are some features that make LabVIEW as a major development tool in the M&T field such as [56], [71], [79], [97], [99], [112]:

1. It simplifies the process of controlling data between computers and external instruments or device.

2. The large number of algorithms that come with the software as pre-made VIs.

3. The ability to incorporate code from other programs into LabVIEW VIs

4. The ability to develop VIs that replace the physical instruments.

5. Add-on LabVIEW feature simplifies the complex development tasks.

6. Due to the graphical nature of the LabVIEW programming language, new programs can be created quickly and with ease.

7. LabVIEW has the potential to be ported between different operating system as it is an independent platform. However, the compiled code created by LabVIEW for each VI is not platform independent and can be executed only by the LabVIEW execution system.

8. LabVIEW-based data acquisition has the ability to download the acquired data into the Microsoft Excel as that should enables laboratory activities very user friendly since students may easily download the experiment collected data into their reports through the Excel program.

9. For the remote operation applications, LabVIEW can be used to perform data acquisition and remotely control hardware devices through the internet.

10. LabVIEW front panel displays the real-time results and allows storage of acquired data for later processing.

11. LabVIEW comes with many internet capabilities that allow a user to publish a static report on the internet, share data for processing, data storage, or data monitoring.

Over all that, LabVIEW has solutions for number of engineering applications provided to the user by the LabVIEW program developer [67]. To make the picture of the LabVIEW clear, it is worthy to mention that there are two technical blocks come with this program [71]. Firstly, the generated codes are not portable across different platforms. Secondly, in order to execute the VI codes, the user needs the run-time environment and therefore a run-time license is required which can be a problem especially when LabVIEW is used for teaching purposes. Furthermore, it has been found that, if the input channels to a slower computer were sampled continuously, LabVIEW is not able to display real-time data as the Analogue to Digital Converter (ADC) buffer overflows [79].

3.3 VI Development

As it has been stated in the previous chapters of this report, LabVIEW-based VIs will replace the physical M&T instruments of the test-rig. The following sections of this chapter explain the steps of the VIs design and development. The physical M&T instruments and control devices that have been used in this study are:

1. The NANOVIP Plus
2. The digital load cell
3. The DAQ card
4. The load control box

The measurement process of this system can be summarised as follows:

1. Firstly, the test-rig parameters are measured by the individual M&T instrument connected to the system (NANOVIP Plus, DAQ and the Load Cell). The nature of the readings is dynamic and they are displayed on the individual instrument screen.

2. Secondly, and after interfacing all instruments with the local computer, the computer sends commands to individual M&T instrument, by means of RS-232 cable, IEEE-488 cable, and USB or DAQ card to get the different parameters readings. Based on the port number assigned to the individual instrument, the commands are transferred through the interfacing means to the corresponding instrument, which interprets the commands and takes appropriate actions like setting up initial conditions or taking measurements or transmitting the measured data to the local computer.

3. In the last step, the readings will be transferred from the individual M&T instrument to the local computer and will be presented on the computer screen according to the VI designed.

4. Based on the readings collected and shown on the computer, a person on duty will decide of which control actions should be taken.

5. The above steps are repeated in sequence for each measurement cycle.

3.3.1 NANOVIP Plus

The NANOVIP Plus is a digital and hand-held portable instrument capable of measuring many fundamental parameters of power system such as the voltage, the current, the power, the power factor, the apparent power and so on [113]. It makes

the serious power quality analysis more feasible than ever before [113]. This instrument can be used for measurements of both single-phase and balanced three-phase systems [113]. It is supported with an RS232 serial interface set-up for serial communication with computers. In this study, the NANOVIP Plus instrument has been used to monitor the change on the IM parameters such as the Voltage (V), the current (I), the Power (P) and the power factor (pf). This instrument has been manufactured to have three leads that are connected to the system for the measurement purposes; two banana-type leads which are connected for the voltage measurement and the third lead is a clip-type for the line current measurement. The connection of this instrument with a single phase and three phase system is shown in Figure 3-4 [114]. As the system under study is a 3-phase system, the three phase connection has been used.
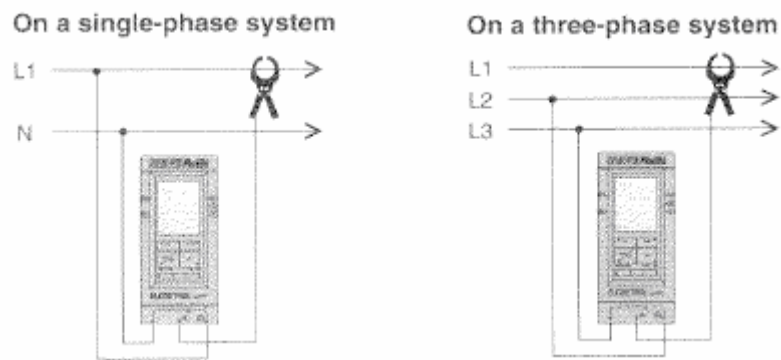
Figure 3-4 the connection method of NANOVIP Plus for both single and three phase measurement

In order for the computer to communicate and gather the different measurements data recorded by the NANOVIP Plus, different sub-VIs have been designed. The nature of the measurement data collected by the NANOVIP Plus of the system parameters enters the computer in a string format, jumbled and difficult to understand. The most common character set of the string format in western world is the American Standard Codes for Information Interchange (ASCII) [26]. The string needs to be reformatted into useful and understandable mean by following the instrument manufacturer recommendations. Therefore the VIs that have been designed to communicate with this instrument have passed through different stages as follows:

1. Stage1. Communicate with the NANOVIP Plus instrument and extract the measurement data it has.

2. Stage2. Split the string format data into different sub-strings carrying

the individual parameter reading. This step is designed according to the instrument manufacture technical support.

3. Stage3. Reformat the sub-strings into useful meaning and take out the individual parameter reading from the main string.

4. Stage4. Present the new formatted data in a friendly format as per the user need.

5. Stage5. Repeat step three for the same number of the measurement parameters. i.e. in this study it was repeated four times to get the readings of (V, I, P, pf).

Since the NANOVIP Plus instrument is supported with a serial port communication interface, a VI for the serial communication has been designed. LabVIEW communicate with a serial-based instrument as follows:

1. Initialise the serial port, specified in the port address, in which the M&T instrument is connected.

2. Enter the instrument ASCII string in the specified port for request of the measurement data available in that instrument. After the instrument received that ASCII string, it will replay automatically with the data it has gathered from the system.

3. Once the instrument reply has been received, the communication with the instrument is closed.

The above steps are repeated each time the measurement data needed to be collected from the instrument. As soon as the computer has established a communication with this instrument, it will continue transmitting the measurement data it collects from the system until the process is stopped by the user. Since the test-rig is a dynamic system, the parameter readings are changing with any change in the system. The above listed steps are illustrated in Figure 3-5.
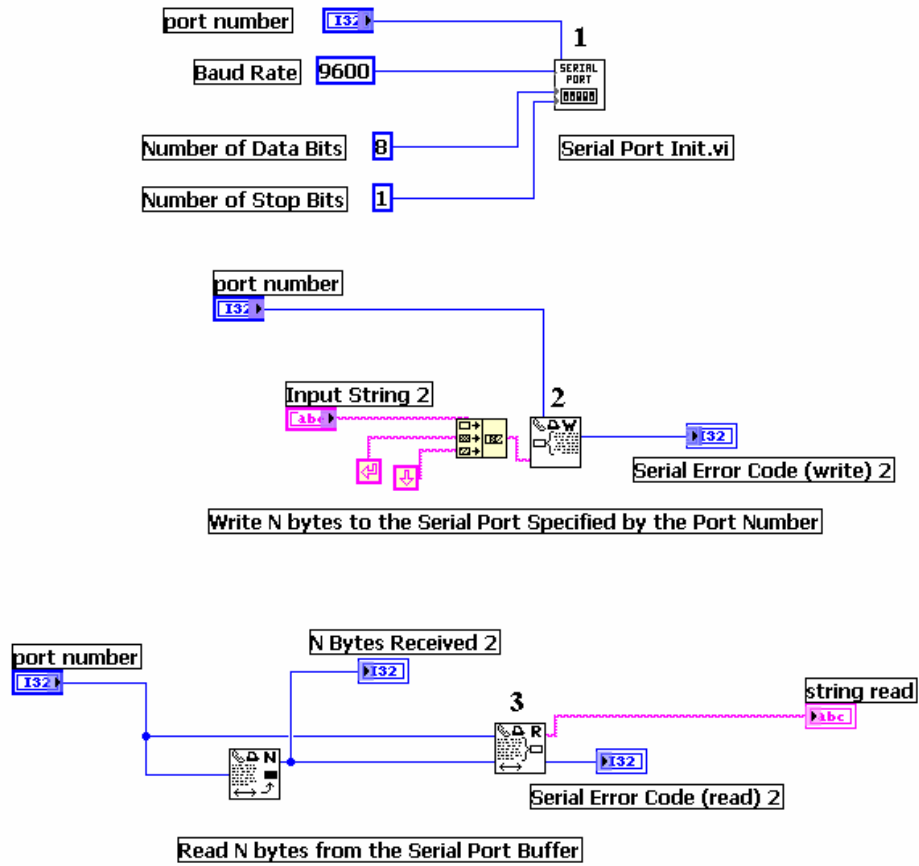
Figure 3-5 block diagram of the Sub-VI that interchange data with a serial port-based instrument or device

3.4 VI Development for the Measurement of the Voltage, Current, Power and Power factor

3.4.1 The Development of the Sub-VI for the Phase Voltage Reading

The NANOVIP Plus M&T instrument transmits all its measurement readings to the local computer by the mean of the serial port. The measurement data enters the computer as it is shown in Figure 3-6. However, not all of these digits shown in Figure 3-6 are required in our study and thus the LabVIEW-based VI has been designed to split these digits and select the reading digits of the voltage, current, power and power factor. The selection of each reading digit is done according to the instrument manufacturer recommendation.
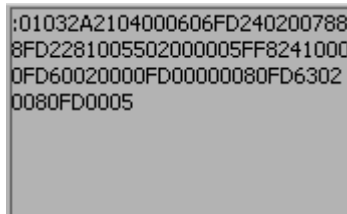
Figure 3-6 String Format for the Measurement Data from the NANOVIP Plus

The main LabVIEW function used to reformat the digits in Figure 3-6 is Search/Split String function shown in Figure 3-7.
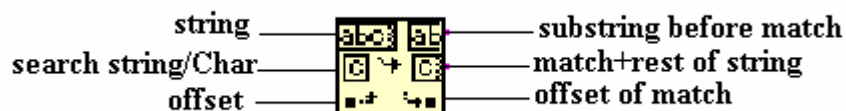
Figure 3-7 Search/Split String sub-VI [115]

This function splits the string format data into two substrings: a substring before the offset (substring before match) and a substring after the offset (match + rest of string) [115]. The input and output pins characteristics of this function are as follows [115]:

1. String: the input string that this function searches or splits.
2. Search string/char**:** the string or character to search for in the string**.** If it is unwired or it contains an empty string, the function splits the string at offset. Either search character or offset must be wired**.**

3. Offset**:** the starting position of searching or splitting and must be numeric.

4. Substring before match: the portion of the string before search string/char or before offset, if this is unwired**.**

5. Match + rest of string: consists of search string/char and all subsequent characters in string.

6. Offset of match: the position of search string/char in string**.**

Figure 3-8 is the block diagram for the sub-VI that has been designed and developed to read the voltage from the data format shown in Figure 3-6.
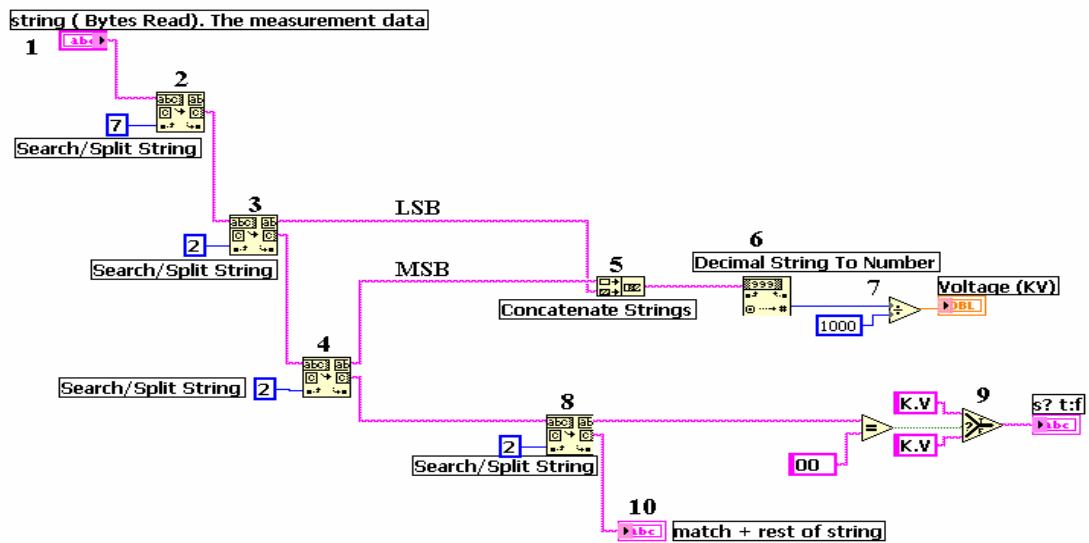
Figure 3-8 block diagram of the Sub-VI for the voltage reading

As it can be seen in Figure 3-8, the design of this sub-VI has passed through the following steps:

1. Through the serial port, the local computer receives the measurement data from the NANOVIP Plus instrument in a string format. This string then was applied to the Search/Split function.

2. The incoming string was divided into two substrings by the use of the Search/Split String function.

According to the manufacturer technical support of the NANOVIP Plus instrument, the first offset of Search/Split string function is seven [116]. It means the function will split the incoming main string data into two substrings: a substring contains the first seven digits and a substring contains the rest of the main string. The first substring (seven digits) is un-useful in our measurement system and thus it was passed over. These seven digits are the first seven digits in Figure 3-6 (: 01032A).

3. The second substring resulted from the splitting in step two; Figure 3-8, was

applied again to the same function (Search/Split String) as an input string but with an offset number of two. The two substrings that produced from this step were a substring contains the first two digits of the main string and a substring contains the rest of the main string. The first string with the two digits (offset) represents the Least Significant Bits (LSB) of the voltage reading. These two digits were the digit eight and the digit nine (21) in Figure 3-6.

4. The second substring produced from step three; Figure 3-8 was applied again to the same function. The two substrings resulted in this step were a substring contains the Most Significant Bit (MSB) of the voltage reading (two digits) and a substring contains the rest of the main string. These two digits were the digit ten and the digit eleven (04) in Figure 3-6.

5. The first substring resulted in step three and step four; Figure 3-8, which represent the LSB and MSB respectively of the voltage reading, were concatenated together. This step is performed by a function called Concatenate String, which is shown in step five; Figure 3-8. This function concatenates the two readings (MSB & LSB) together in the order of their connection to form the voltage reading (04 & 21). However, the voltage reading up to this step is still in the string format.

6. The voltage reading resulted from step five; Figure 3-8 was applied to a function of Decimal String to Number. This function converts the numeric characters in the string to a decimal integer and returns it in a number format [115]. In this study, the number format was (0421).

7. The second substring produced from step four; Figure 3-8 was applied as an input string to the function in step eight; Figure 3-8 with an offset of two. The two substrings produced were a substring with the first two digits and a substring with the rest of the input string. The first substring is used to determine the measurement unit of the voltage as it is shown in step nine; Figure 3-8. According to the manufacturer technical support, if these two digits are (00), then the voltage measurement unit is Volts (V) [116]. However, since the result from step six is divided over 1000, the voltage unit will be always shown in kilo-Volt (kV).

8. The second substring from step eight; Figure 3-8 carries the rest of the measurement data from the original main string after the voltage reading was extracted. This substring will be applied to the next stage to get the reading of

the other parameters of the system.

3.4.2 The Development of the Sub-VI for the Current Reading

The second parameter measured by the NANOVIP Plus is the current. Its reading comes after the voltage reading in the main string data of Figure 3-6. The current reading was passed almost through the same steps as the voltage reading. The input strings for this sub-VI is the last string that was produced by the phase voltage sub-VI in Figure 3-8. The block diagram of the sub-VI that has been designed to process the current reading is shown in Figure 3-9.
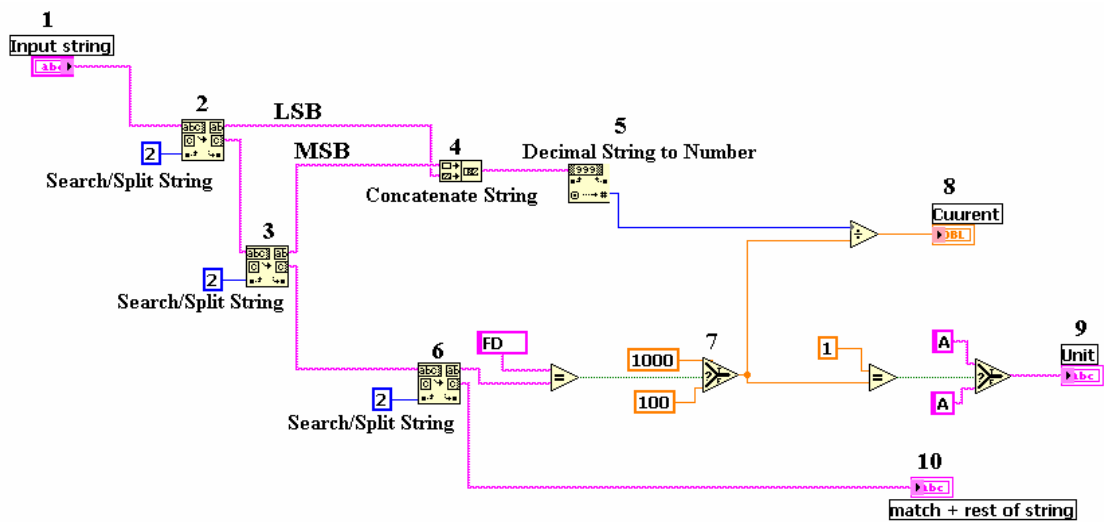
Figure 3-9 block diagram of the Sub-VI for the current reading

This sub-VI works as follows:

1. The second substring resulted in step eight; Figure 3-8 is the main input string for this sub-VI as it is shown in step one of Figure 3-9.

2. The input string is again applied to the Search/Split String function with an offset of two. The two substrings produced were a substring with two digits and it represents the LSB of the current reading in step two; Figure 3-9 and it is (06). The second substring is the rest of the input string.

3. The second string from step two is used in step three with an offset of two produced two substrings: a substring with two digits represents the MSB of the current reading in step two; Figure 3-9, and a substring with the rest of the input string. The MSB was (06) in Figure 3-6.

4. The MSB and LSB were concatenated together to make the current reading as it is shown in step four; Figure 3-9. The result was applied to the Decimal

String to Number function to convert the string format to numerical number format as it is shown in step five; Figure 3-9. The result of this step was 606.

5. To determine the measurement unit of the current, the second substring resulted in step three; Figure 3-9 was applied to the split string function with an offset of two. The two substrings produced were a substring with two digits and a substring with the rest of the string. The first substring in this step determines the current measurement unit. According to the manufacturer hints, if this substring digits is FD the measurement unit is mille Ampere (mA) while if the two digits are FE the unit is Ampere (A) [116]. However, this sub-VI has been designed and modified to show the unit of the current in Ampere (A) for all cases. The program performs internal conversion for the unit different than Ampere (A).

The second substring in step six; Figure 3-9 was carried for the next stage reading to get the readings of the power and the power factor.

3.4.3 The Development of the Sub-VIs for the Power and Power Factor Readings

Power and power factor are two of the main parameters in power system measurements. In this study, they have been measured by the NANOVIP Plus M&T instruments. The block diagram of the sub-VIs for the power and power factor measurements are shown in Figure 3-10 and Figure 3-11 respectively. The two sub-VIs were passed through the same steps as the voltage and current sub-VIs.

The unit of the power is determined according to the manufacturer hints. If the two digits of the substring in step six; Figure 3-10 are (00), the measurement unit is watt, alternatively, if the two digits are (01) then the measurement unit is in kilowatt (k.Watt) [116]. However, the program has been designed to show the measurement unit of the power reading in kilowatt continuously through an internal conversion.

For the power factor reading, the sub-VI for this reading also was passed through the same steps which can be summarised as follows:

1. Split the incoming string into two different strings based on the offset number and according to the manufacturer instructions.
2. Find the MSB and the LSB of the reading.
3. Concatenate the MSB and LSB strings to get the total reading.
4. Apply the result from step two to the Decimal String to Number function.

5. Determine the measurement unit of the reading as per the manufacturer description.
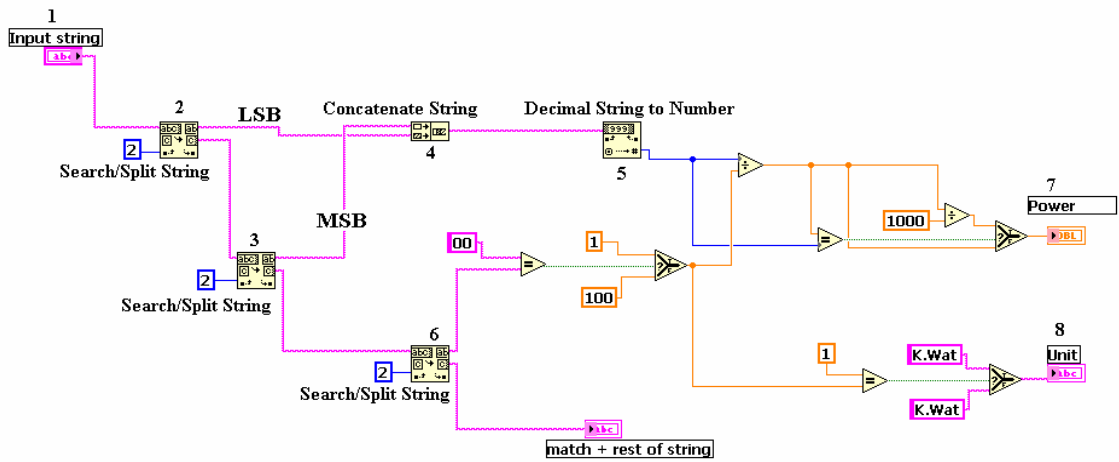
Figure 3-10 block diagram of the Sub-VI for the Power reading
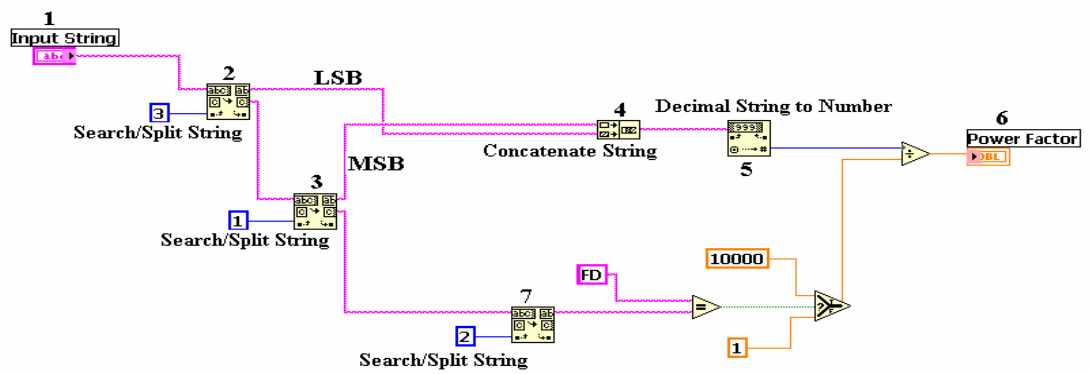
Figure 3-11 block diagram of the Sub-VI for the Power factor reading

3.5 IM Rotational Speed Measurement

Normally, the tachometer instrument is used to measure the IM rotational speed. A digital tachometer is used in this study to measure the IM rotational speed. The tachometer is connected to the IM shaft by the use of the BNC-connector. It shows the IM rotational speed-reading in the unit of the Revolution Per Minute (RPM).

To read the speed measurement of the IM from the local computer, the motor shaft has been interfaced with the computer by means of DAQ card through the NI BNC-2110 academic starter kit shown in Figure 3-12.

Figure 3-12 NI- BNC-2110 Academic Starter Kit [117].

The LabVIEW main function that has been used to design the VI system to measure the IM rotational speed is a Measure Pulse-Width or Period shown in Figure 3-13. It measures the pulse-width (length of time a signal is high or low) or period (length of time between adjacent rising or falling edges) of a TTL signal connected to the counter's GATE pin [115].
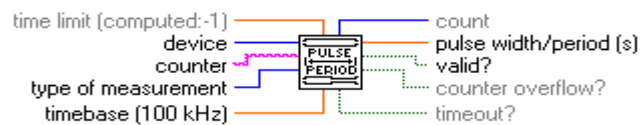
Figure 3-13 Measure Pulse-Width or Period sub-VI [115]

The job performed by each pin of this function is as follows [115]:

1. Device: the device number assigned to the DAQ device during configuration.

2. Counter: identifies the counter(s) the VI configures.

3. Type of measurement: identifies the type of pulse-width or period measurement.

4. Time-base: the internal clock signal to use (default 100 MHz). If the

3-52

counter overflows because time-base is too high, it has to be lowered until a valid reading occurs or until the lowest time-base is used and a timeout occurs.

5. Pulse-width/period (s): the measured pulse-width or period of one revolution as it is shown in Figure 3-14.
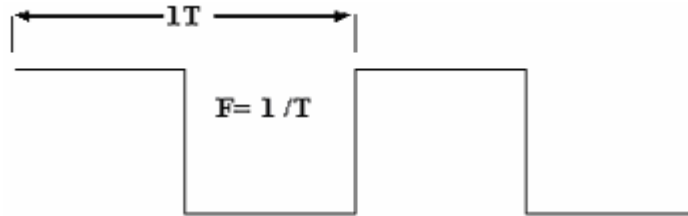
Figure 3-14 the measurement of 1-pulse (revolution) duration

The sub-VI which has been developed to read the IM rotational speed is shown in Figure 3-15.
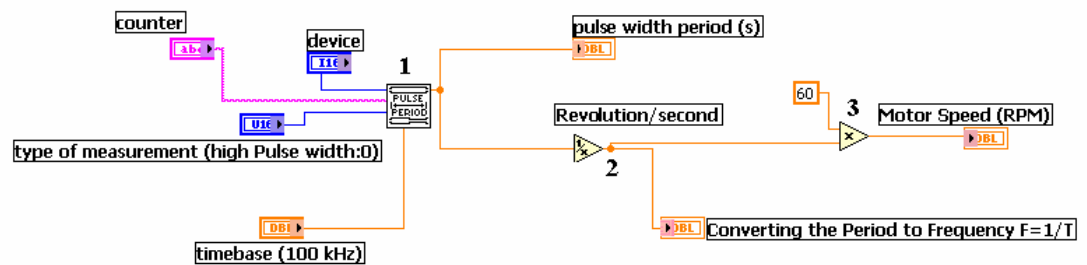
Figure 3-15 block diagram of the Sub-VI for the rotational speed reading

This sub-VI works as follows:

1. After connecting the main pins of the function in Figure 3-13 and configure them with the local computer, the sub-VI measured the pulse-width or period of each revolution of the IM shaft.

2. Since the frequency is the reciprocal of the period and it means the number of signal occurrence per the unit of time, the step two of Figure 3-15 gets the number of the Revolution Per Second (RPS).

3. Normally, the measurement unit of the rotational speed is expressed in term of the RPM, thus the result from step two, Figure 3-15 was multiplied in sixty to convert the unit of RPS to RPM as it is shown in step three of Figure 3-15. Consequently, the result of step three is the IM rotational speed in RPM.

3.6 Torque Measurement

Initially in the test-rig of this study, the torque developed by the system is measured by an analogue torque meter. In order to build the Computer-based Instrumentation System C-bIS, the analogue meter has been replaced by a digital load cell that supports the computer interface. Load cells are the heart of many weighing systems [118]. They come in different designs and shapes to meet different applications of different users. The type that has been used in this study is a bending type and digital load cell from TRANSCELL Technology Company that is shown in Figure 3-17. It is supported with RS-232 interface and has a programmable general purpose and industrial grade weight digital indicator configured to show the reading in two different units; kilogram (kg) or Pound (lb) as per the user need [119]. In order to adopt this cell for different applications, it has to be configured according to the manufacturer recommendations [119]. The front panel of the digital indicator is shown in Figure 3-16.
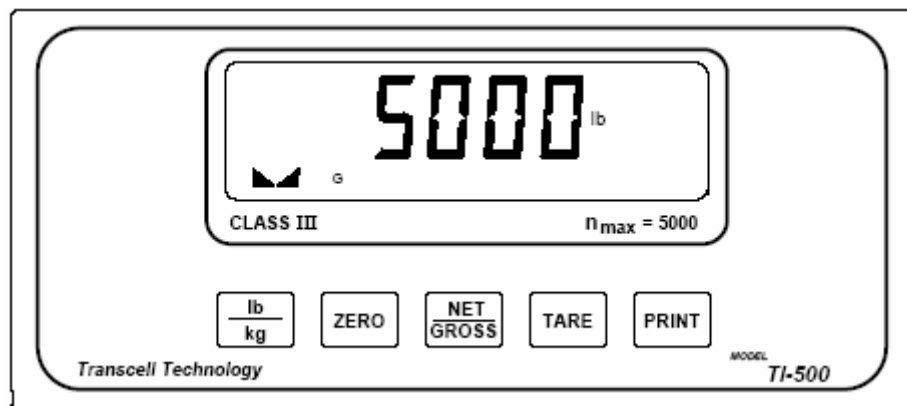
Figure 3-16 front panel of the digital indicator illustrating all the function keys [119]

The system-developed torques is measured from the load side, which is from the DC-Dynamometer in this study. The load cell is physically hooked with the generator shaft via a lever of 30cm in length. The load cell has a U-shape holder in which the lever is fixed. This lever is fixed with the generator shaft from one side and with cell from the other as it is shown in Figure 3-18.

Figure 3-17 the photo of the digital load cell from INTERFACE
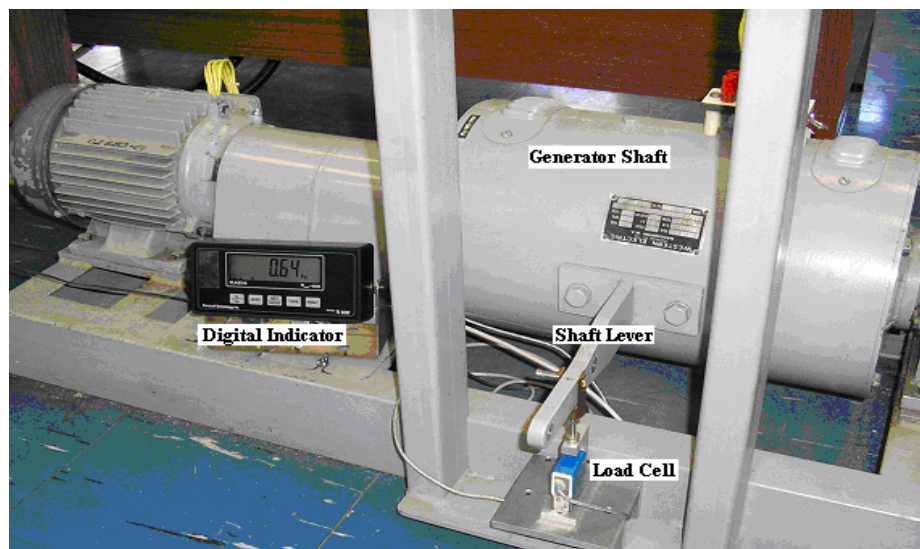
Figure 3-18 the connection between the load cell and the generator shaft

The programmable digital indicator provided with the load cell is a multi-purposes use. To find the developed torque from the shaft rotational force, the sub-VI in Figure 3-20 has been designed to perform the following mathematical calculation as it is shown in Equation 3-1:

$$F = m * a$$
$$T = F * d$$

Equation 3-1 Developed torque calculation

1. Firstly, the mass is multiplied by the acceleration to get the applied rotational force (F).

2. Since the torque is determined by multiplying the applied force into the distance (lever length) from the rotation point (shaft) to the point where the force is applied (load cell) thus the result from step one is multiplied into the lever length. The result of this multiplication is the torque in Newton. meter (N.m).

The serial data format from the load cell to the digital indicator is as it is shown in Figure 3-19. The sub-VI that interchange data with the load cell has been designed to reconfigure and reformat this format to a readable format.
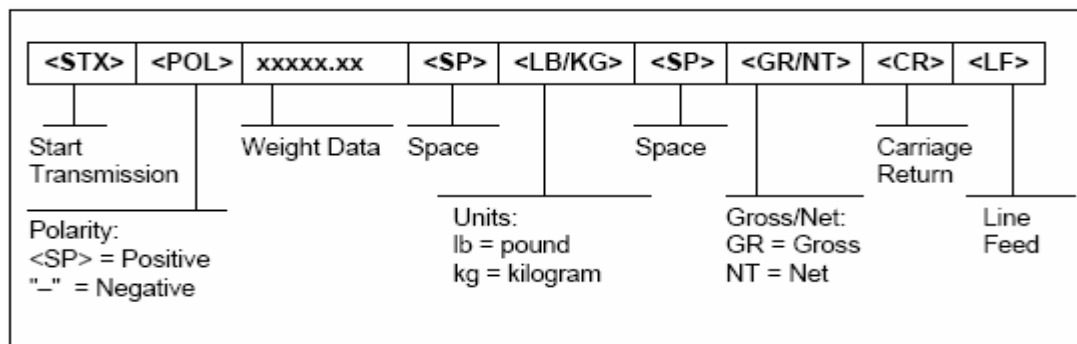
Figure 3-19 the serial data format of the load cell [119]

The trick in this part was in the load cell interface with the computer as the cell has a serial port interface. Normally computers have two serial ports only which is the case with the local computer being used in this study. Both ports are reserved; one for the computer monitor and the other for the NANOVIP Plus instrument. It means we need to have more serial port points. To have so, a serial to a USB adaptor has been used to make use of the available USB ports. This adaptor adds more serial port to the computer through the USB connector and as a result of that; the load cell has been interfaced. The sub-VI which has been developed for the torque measurement is shown in Figure 3-20. This sub-VI works as follows:

1. Through the computer USB port, the measurement data from the load cell is gathered. It enters the computer in a string format as it is the case with the NANOVIP Plus.

2. The string format was then applied to the Search/Split String function which has been explained previously. It splits the incoming string into two substrings with an offset of five. The first substring is un-useful for the measurement of this study and thus it was skipped over. The second substring from step one, Figure 3-20 was applied again to the same function as an input string with an offset of six.

3. The result from step two, Figure 3-20 was two substrings; a substring before the offset was carrying the mass reading (inertia) as it is shown in step three; Figure 3-20. The second substring was ignored.

4. The mass reading in step three, Figure 3-20 was accompanied with mass unit (kg or lb). Therefore, the mass value and the mass unit have to be separated from each other and thus it was applied again to the search/split string function with an offset of four as it is shown in step four.

5. The two substrings resulted in step four, Figure 3-20 are the mass value and the mass measurement unit. The mass value was converted from string format to a numerical number format by the use of the Decimal String to Number function as it is shown in step five, Figure 3-20.

6. According to Equation 3-1, the mass value has to be multiplied into the gravitational acceleration ($a = 9.8$ m/s^2) as it is shown in step six, Figure 3-20. From there the rotational force was calculated which in turn is multiplied into the lever length (0.3m) to get the torque in Newton-meter (N.m) as it is in step seven, Figure 3-19.

7. In order to compensate the difference between the two units; kg and lb so they will not vary the torque value, the sub-VI has been designed to compare them and make the required compensation. That has been achieved by applying the second substring from step four; Figure 3-20 to a comparison function thus converts the lb to kg.

Generally, there is a direct relation between the system developed torque and the motor speed. From the basic electrical machine theories, if the torque applied to the motor shaft is known, the rotational speed can be calculated. Alternatively, if the motor rotational speed is known, how much torque should be applied can be calculated.

The difficulty that has been faced and solved in this part is the offset numbers of the individual string reading from the load cell. As it has been explained with the NANOVIP Plus instrument, there are manufacturer hints for the numbers of the offset for each step by which the main string is split in order to get the final reading. This scenario was not applied to the load cell as there are no technical hints from the manufacturer. That is because the load cell being used is of a general use and for each particular application the user has to configure it.
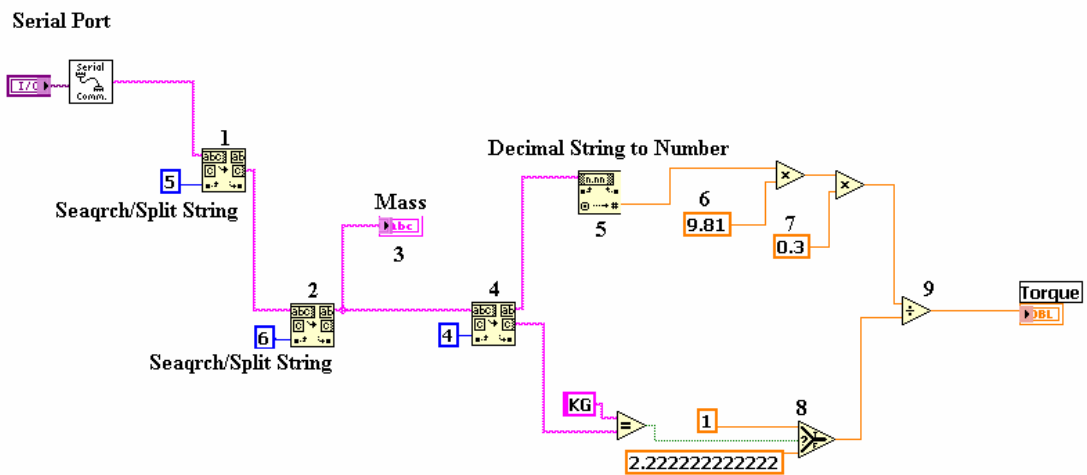
Figure 3-20 block diagram of the Sub-VI for the system developed torque reading

3.7 The System Load and the Load Control Box Design and Development

As it has been mentioned previously in this report, the DC-Dynamometer acts as a variable load to the IM. The value of the load is increased in five steps till it reaches the rated (maximum) value. In order to interface the DC-Dynamometer with the local computer and control it without making any change to its structure or its connection with the IM, an in-house designed and developed load control box has been used to drive the system load. Furthermore, the DC-Dynamometer load has been replaced by an external load bank. The load value has been designed and chosen according to the DC-Dynamometer specifications and rated values given in its panel as follow:

Power = 2.24 K.w   V= 220 V   I= 12 A

Since there are five load paths, the current carried by each path is:

$$I_{path} = I_{total} / number\ of\ paths$$

Equation 3-2 a path current calculation

From Equation 2 we get: I = 12/5 = 2.4A

The rated power is 2.24K.w. Since the power equal

$$P = R * I^2$$

Equation 3-3 dc power calculation

Applying Equation 3 lead to: 2240= R* (2.24)^2 which give R= 388.89 Ω

This is the equivalent resistor of each path. Therefore the resistor per a single path is: R_{path}= 388.89 / 5= 77.78 Ω

Based on the above calculations, the load that has been chosen was a 77.8 Ω resistor and it can sustain a current up to 2.4 A. The load control box is connected to the local computer, through the computer SPP from one side, and from the other side through terminals, is connected to the DC-Dynamometer. The internal design and structure of this box is shown in Figure 3-21. As it is shown in that figure, the box contains several elements which are:

1. Two AC computer-controlled Solid State Relays (SSR) and five DC computer-controlled SSR from CRYDOM Company.

2. A buffer. It has two main tasks: to amplify the computer signals and to protect the computer from any error could take place in the test-rig side.

3. Grounding resisters (1kΩ). These to ground the computer signals otherwise the signals will float and will create disturbance to the test-rig as the signal will switch between high and low values.

4. Transient Protection Diodes (TPD): as per manufacturer of the DC-SSR recommendation, an inductive load will produce harmful transient voltages when it is turned off [120]. Therefore, to protect the DC-SSR from the transient state, diodes that can resist voltage in the reverse direction without breaking down and starting to conduct greater than the supply voltage, are connected across the load. The supply voltage in this case is the DC-Dynamometer rated voltage value.

In Figure 3-21 the bottom five relays are the DC-SSR while the top three relays are the AC-SSR. The buffer, TPDs and the grounding resisters can be seen as well.
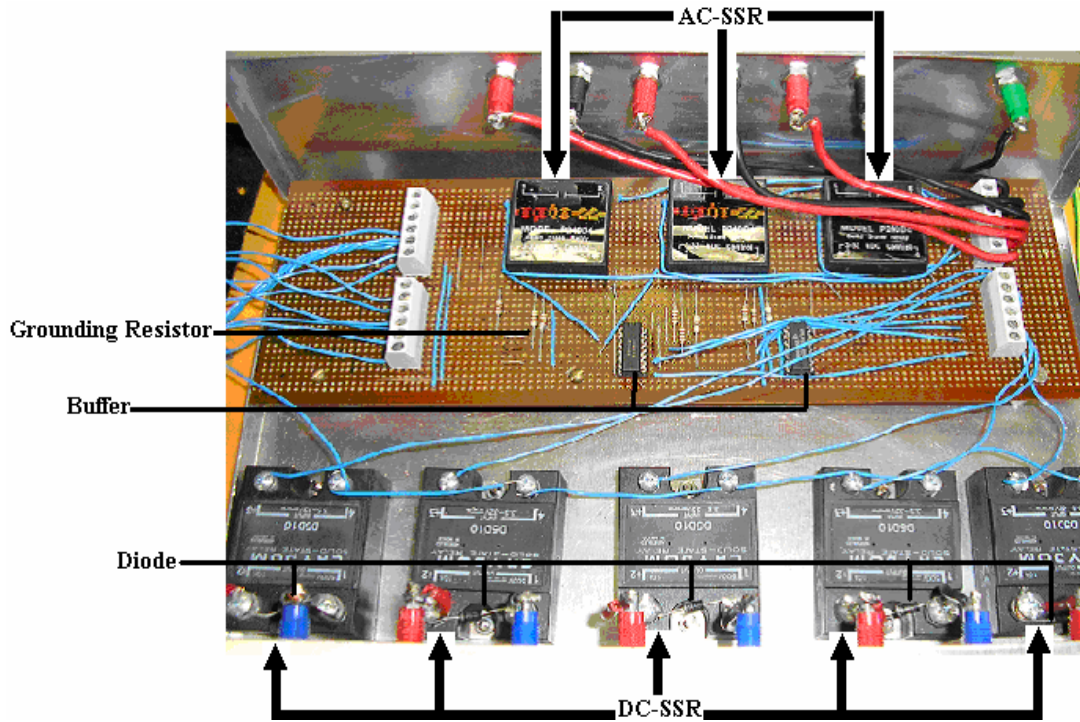
Figure 3-21 Internal connection of the load control box

The two AC-SSRs have been used as follows:

1. SSR #1 has been used to replace the SIS in the IM panel side. This switch is the first to be energised. It connects and disconnects the test-rig with the external power supply.

2. SSR #2 has been used to replace the LIS in the DC-Dynamometer panel side. This switch is the second to be energised as it connects and disconnects the load to and from the IM.

The schematic diagram of the load control box design is shown in Figure 3-22. This control box works as follows:

1. Control commands are initiated from the local computer through the computer SPP which has eight pins data and each pin is connected to a specific SSR.

2. After the commands have been driven from the computer, a buffer, which is connected between the computer SPP and the SSRs, filters and amplifies the computer signals. To some extent this buffer acts as a signal conditioning circuit to the computer signals. Beside that it protects the computer from any faults could occur in the high voltage side (DC-Dynamometer).

3. Depending on which pen of the SPP was energised; the assigned SSR will be activated accordingly which in turn connects a single load from the load

bank. There is no specific sequence to be followed for the DC-SSRs to be energised and thus any of these relays can be energised or de-energised at any time.

4. The system performance changes alongside with the load change. This change is monitored through the VIs on the computer.
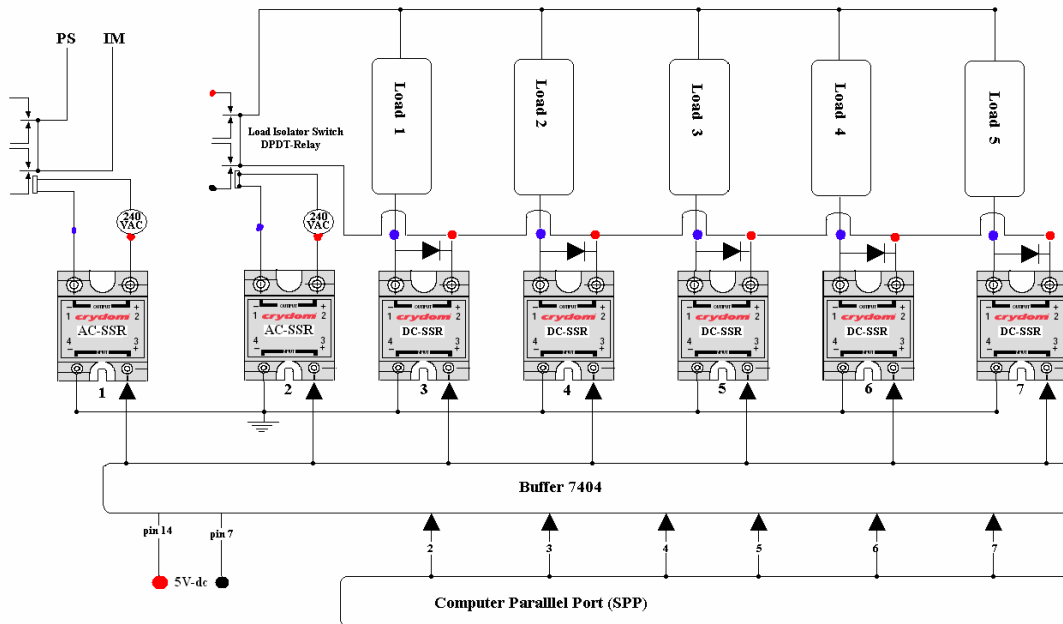
Figure 3-22 the internal design and structure of the load control box

The main LabVIEW function which has been used to communicate with a SPP-based instrument is the out port function shown in Figure 3-23. This function transmits the value, written in the write value terminal, to the out port specified by the address terminal [115]. The sub-VI which has been designed to handle the communication between the user and the control box is shown in Figure 3-24. As it can be seen in that figure, this sub-VI passed through three steps in order to communicate with the system as follow:

1. Specify the SPP base address. The out port address can be found on the hardware configuration of the computer being used. The procedures of how to specify and configure the SPP of any computer is appended at the end of this report.
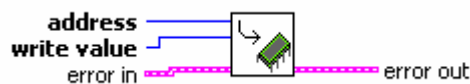
Figure 3-23 Out port function for the SPP communication [115]

3-61

2. Send the control commands to the specified SPP. The control commands are handled by the use of the Boolean switches. There are eight Boolean switches shown in the program front panel allocated as follows:

- One switch for the SIS which is used to energise or de-energise the test-rig from the external power supply.
- One switch for the LIS which is used to connect and disconnect the load from the test-rig.
- Five load control switches (L1-L5). Each switch connects and disconnects the five DC-SSRs and the five load units from the load bank.
- One unconnected extra Boolean switch is kept for the future modification.

3. The control commands that have been initiated by the Boolean switches are appended together by the use of the Build Array function. This function appends all inputs in order, forming an output array of the same dimensionality as the highest-dimension array input wired [115].

4. The data array comes out of the build array function is in the Boolean format as Boolean switches has been used to initiate the commands. This array was applied to Boolean Array to Number function. It converts the Boolean input to a 32-bit unsigned integer by interpreting it as the binary (complement of two) representation of an integer with the first element of the array being the LSB [115].

5. The output from step three, Figure 3-24 was applied to the out port.

6. Through the SPP cable, the commands were transmitted to the control box and then implemented on the system.
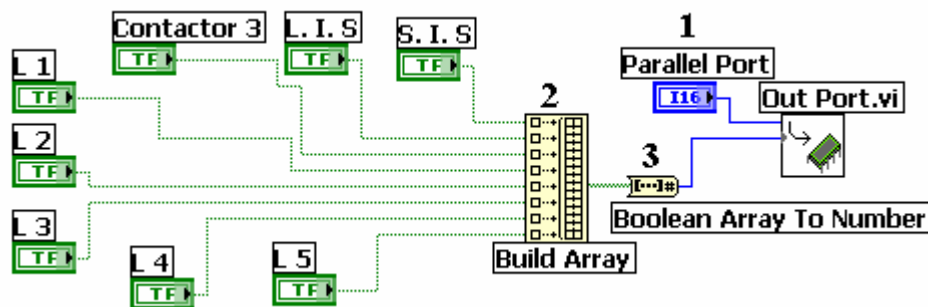
Figure 3-24 block diagram of the sub-VI for the SPP communication

4 System Implementation

4.1 Introduction

The work that has been carried out and shown in chapter three was to prepare the research test-rig. After the system hardware has been successfully interfaced with the local computer, and after the system VIs have been developed using the LabVIEW program, it is the time to examine and run the research test-rig in order to achieve the research goals. The individual sub-VI which has been developed in chapter three were combined together under one frame called While Loop function shown in Figure 4-1 in order to form the main VI block diagram of this system. The work of the While Loop function is controlled by two elements; loop iteration and loop control [115]. The iteration (**i**) terminal provides the current loop iteration count, which is zero for the first iteration [115]. While loop function repeats the sub-VIs inside it, at least once, until the operator change the loop condition from the conditional terminal. While loop function feature supports the continuous data acquisition from the test-rig as it continue running the sub-VIs within it and acquire data from the test-rig till the user changes the loop condition status [115].

Figure 4-2 and Figure 4-3 are the block diagrams of the main VI program of this study. It is clear from these two figures that, the main block diagram includes, besides the individual sub-VIs previously described, some other functions that facilitate the test-rig operation, data acquisition, data processing and data presentation. Other functions and sub-VIs included in the main block diagram is the HELP sub-VI and a sub-VI for open a path for a new file to save the measurement data as a reference or for off-line analysis. The HELP sub-VI contains some useful information about the research test-rig. Furthermore, it gives the operator directions and hints about the program execution during the operation stage.
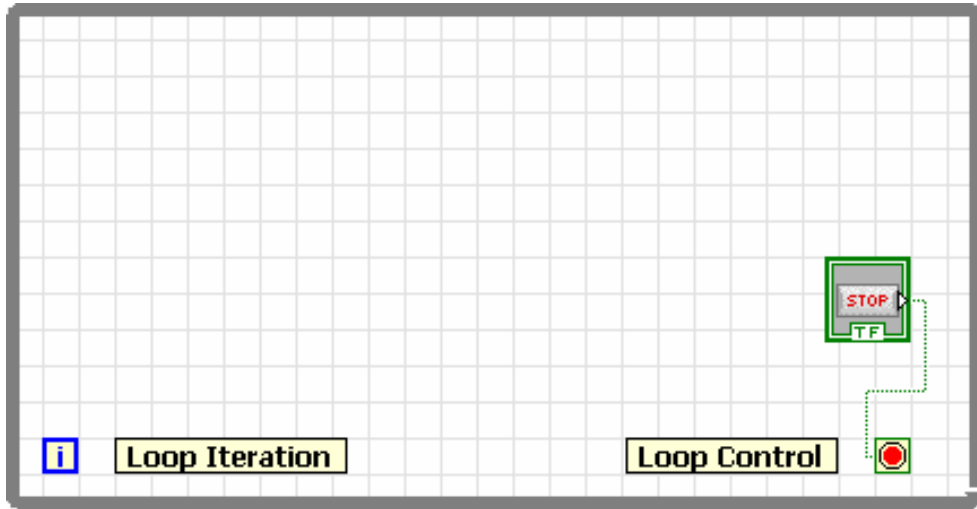
Figure 4-1 While loop function [115]

Part. 1
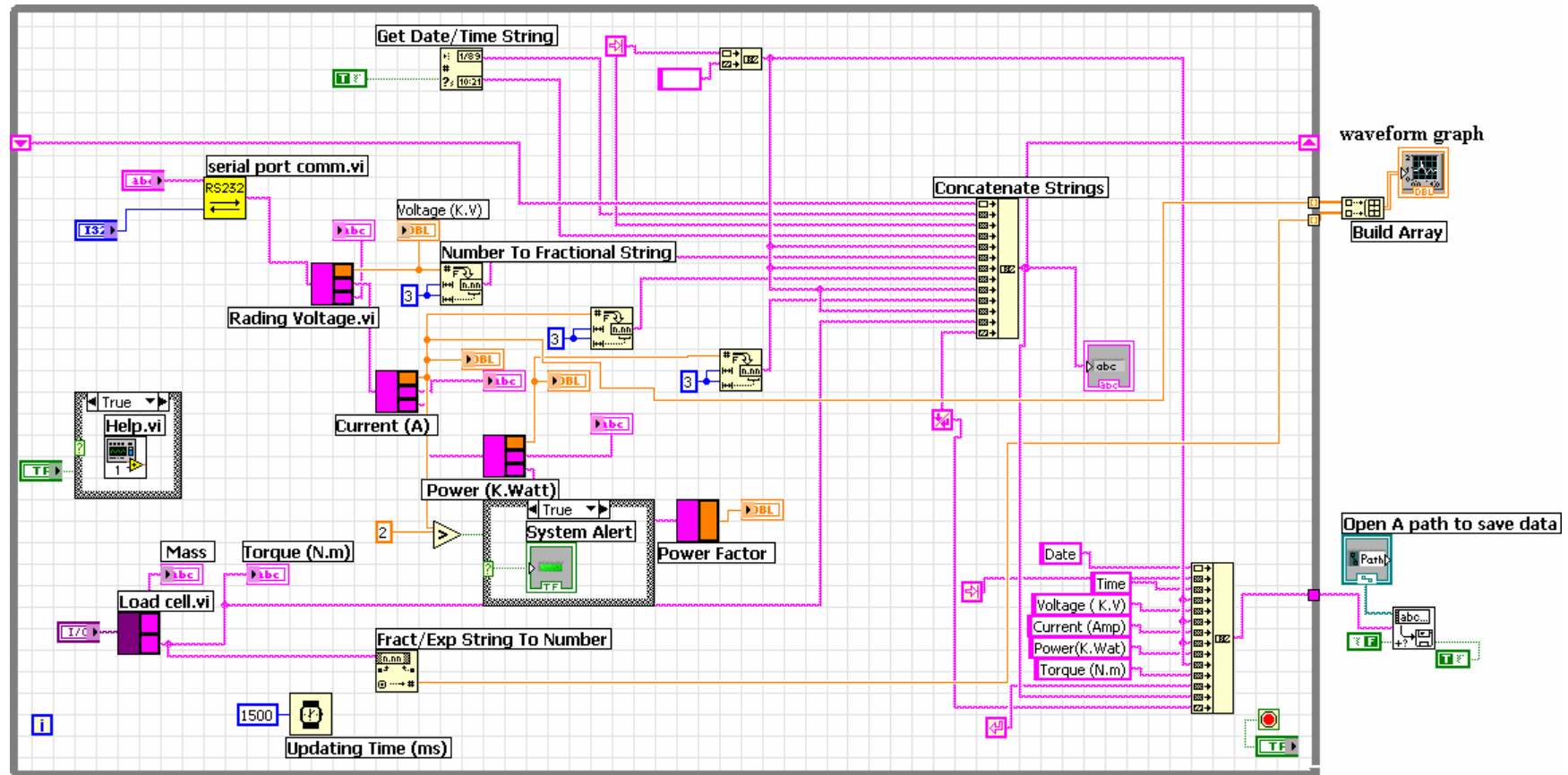
Figure 4-2 Part 1 of the main VI block diagram

Part 2
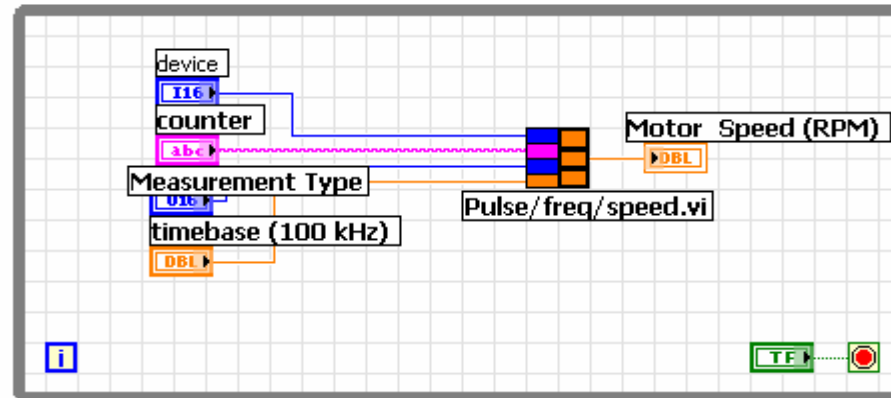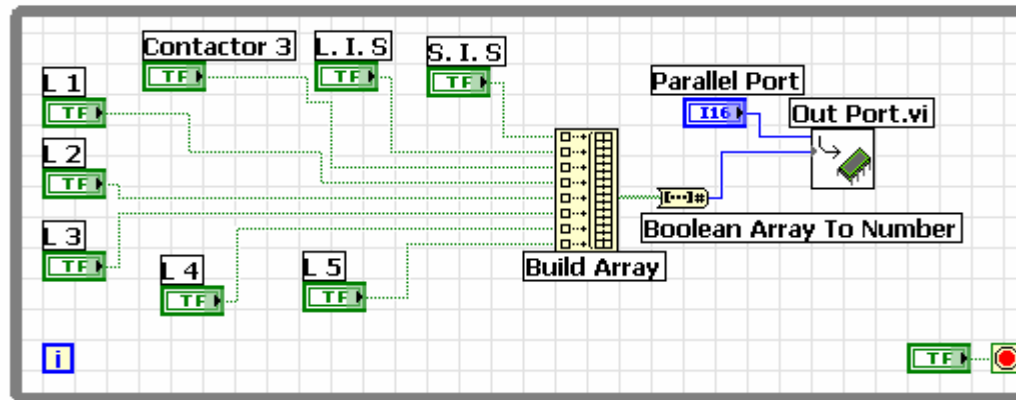
Figure 4-3 Part 2 of the main VI block diagram. The top sub-VI is of the SPP and the bottom sub-VI is of the DAQ for the speed measurement.

4.2 Client/Server Configuration

The philosophy behind this research remote operation is based on the client/server computer configuration. Client/Server as a term was first used in the 1980s in reference to PCs on a network and it started gaining acceptance in the late 1980s [121]. Client/server describes the relationship between two computer programs in which one program acts as the client and requests a service from another program which acts as the server and provide the service [122]. A single PC can be both a client and a server simultaneously depending on the software configuration [122]. With the LabVIEW program, a single computer can be both a client and a server at the same time. The client-server is a common model for the internet-based networked applications [75]. There are different protocols that have been developed for the communication between the clients and the server such as UDP, IP and TCP/IP but the common used among those is the TCP/IP [33]. LabVIEW full version program supports this protocol. With the use of the TCP/IP users can communicate over single networks such as LAN or interconnected networks as the WAN [105]. Therefore as long as there is a network connection between the client and the server, the client can be anywhere [123]. Client/server configuration has been used by many developers and researchers for the remote operation [124], [125], [126], [127], [128]. The structure of the basic client/server configuration is shown in Figure 4-4. There are two types of the client/server configuration; single client and multiple clients [75].

1. Single-client: Servers accept connection with one client at a time.
2. Multiple-clients: Servers accept multiple client connections simultaneously.

The two types of configurations have been applied in different situations. If the application does not support multi-operators simultaneously, the single client configuration is used otherwise the multiple clients configuration can be applied. With the LabVIEW program multiple client operation can be achieved but that requires a special software license [105]. However, with the LabVIEW7 version that has been used in this study, multiple clients can monitor the system operation but only one client at a time can have the control action. A special feature of LabVIEW program is a mechanism that queue different clients and schedule them in a series to have the remote control action of the system [129]. With this mechanism, LabVIEW

signals the former controlling client if there is a request for a control from another clients. It gives the previous controller some time to finish the job and then the control privilege is transferred automatically to the next controller on the queue.

To establish a communication between the client and the server in the client/server configuration, five steps are performed by the VI in the client side [75]. These are as follows:

1. The Client opens a connection with the server.
2. Send commands.
3. Receive responses.
4. Repeat steps 1, 2 & 3 as often as necessary.
5. Close the connection.
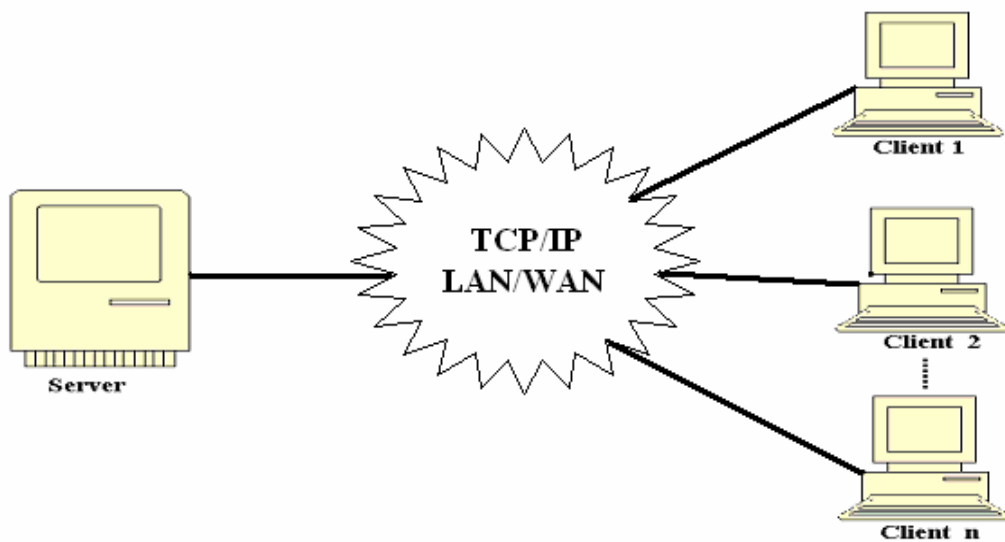
Figure 4-4 Client/Server Configuration

4.3 Local Monitoring and Control Test

To ensure the test-rig is operating as it has been planned and the research goals are achievable; the test-rig has been testified by three different tests at different stages. These to be:

A. Local Monitoring and Control

B. Remote Monitoring and Control
- LAN (intranet)-based
- WAN (internet)-based

The first step in examining the study test-rig was from the local computer located by the test-rig inside the laboratory. The test was fully computerised in which a local user has successfully controlled and monitored the test-rig from the local computer, through the LabVIEW7 front panel, in a real-time basis. The program has been designed in a way that the user, wether local or remote, is able to energise the system, control and monitor the change of the system performance, take real-time data continuously by the use of a fully computerised instrumentation system.

Figure 4-5 and Figure 4-6 are two images were captured form the program front panel. The front panel designed by LabVIEW program has high facilities for the man machine interface. The left side of Figure 4-5 is the control part of the program front panel. It contains controllers, switches, indicators and a path to open a new file where the user can save the measurement data. The first three controllers are used to configure and address the serial port and the SPP. The fourth controller is used to enter the string command (ASCII) of the NANOVIP Plus instrument. The middle four controllers (device, counter, time base and the measurement type) are used to configure and address the DAQ card that measures the IM rotational speed. The bottom eight controllers (SIS, LIS, Cont3, and L1-L5) are used to energise and de-energise the system and the load as they have been explained previously in chapter three. Configuring the M&T instruments in LabVIEW can be done by use either constants or controllers. The main reason behind using controllers and not constants in the configuration of the M&T instruments is to make the program operable with other instruments. In this way, this program can be easily reconfigured for other instruments and devices.

There are three STOP switches 1, 2 and 3 are used to stop the operation of the test-rig safely and without an interruption to the entire system operation. These three

switches have to be pressed in their numbering sequence as the operation of the first switch affects on the second and so on.   Beside the above mentioned controllers and switches, there are a HELP switch and a new file path controller. If the HELP switch is pressed, a new front panel will be opened. It is a sub-VI that contains some information for the users during the running operation. The right side in part one of Figure 4-5 is a waveform graph plotter. It plots graphically the relationship between any different parameters in the system. In this study, this plotter plots the relation between the line current and the system developed torque.

In contrast to the control part, Figure 4-6 of the main front panel is for the monitoring purpose. It contains three analogue meters for the reading of the voltage, current and the power respectively. The three meters are supported with digital indicators for the user to get an accurate and exact figure of the reading values. Beside that, there are two digital indicators to show the reading of the power factor and the system developed torque. In addition to that, there is also an analogue meter gauge supported with a digital indicator to show the IM rotational speed reading.

To simplify the presentation of the test-rig measurement data, the front panel is incorporated with a table. The table arranges the different parameters readings of the system with the date and the time at which the readings were taken. One more feature in this program design is a light indicator assigned for the automatic system alert. It is the green light in part 2; Figure 4-6. This indicator is supported with a controller in which the operator can set the maximum value of any parameter, such as the voltage, the current or others that the system is allowed to reach. The indicator lights if the reading of a certain test-rig parameter exceeds the predetermined value by the system designer. In this study, the indicator is set up to light if the current reading exceeds 20A.

4.3.1   Local Operation Steps

To start with this test, local user or operator should follow certain steps in order to run the test-rig properly and safely from the local computer. These steps should be implemented in the provided numbering sequence as follows:

1. Connect the test-rig apparatus, which have been listed previously, together and with the local computer. The connection detail is described in the appendix of this report. It is recommended that the user asks for technical assistance and supervision for the right connections.

2. Ensure the external power supply that runs the IM is turned ONN.

3. The control box and the high voltage switches (SIS & LIS) are energised by an external power supply. They have to be connected and energised.

4. Open the LabVIEW program on the local computer and go to the test-rig file which is (Last Version Program2.vi).

5. Specify and configure the addresses of both the serial and the SPP ports. The serial port is (0) for the NANOVIP Plus and (3) for the Load cell. The SPP address is 378 for the local computer used inside the laboratory.

6. Enter the ASCII for the NANOVIP Plus which is (:010302020015E3).

7. Specify and configure the DAQ card parameters as follow: (device: 1, counter: 0, time base: 100 KHz, measurement type: measure period).

8. Open a new file to save the measurement data for off-line analysis and future reference.

9. Energise the different M&T instruments.

10. Press the START button on the IM main panel board shown in Figure 4-7.

11. Press the run icon on the program front panel. It is the arrow located on the top left corner on the front panel in Figure 4-5. This will switch the program to the run mode.

12. To energise the system, press the SIS on the program front panel. This replaces the SIS in the IM side shown in Figure 4-7. This switch connects the IM to the external power supply. By this step, the user should be able to see different readings of the IM parameters on the program front panel.

13. To connect the load bank with the IM, LIS has to be switched. This switch replaces the load switch in the DC-Dynamometer front panel shown in Figure 4-8. After that, and depending on how much load is required, loads controllers (L1-L5) can be switched ONN and OFF. The change in the load amount varies the system parameters reading. These readings will be presented on the table.

14. To stop the running of the test-rig, press the STOP switches. First switch stops the running of the sub-VI that measures the IM rotational speed; the second switch stops the sub-VI that controls the SPP. After these two switches were switched OFF, user has to wait until the reading of the parameters (V, I, P, pf, Speed) on the meters returned back to zero position or closer on the meters and then the switch number three can be pressed to

stop the running of the entire program. Following to that, and if the file for saving data has not been specified, a screen to open a file where the measurement data can be saved will pop up and there the data file can be specified. The file can be opened from the normal Excel program as it is shown in Figure 4-12. Furthermore, the relation between some of the system parameters will be plotted on the graph plotter.
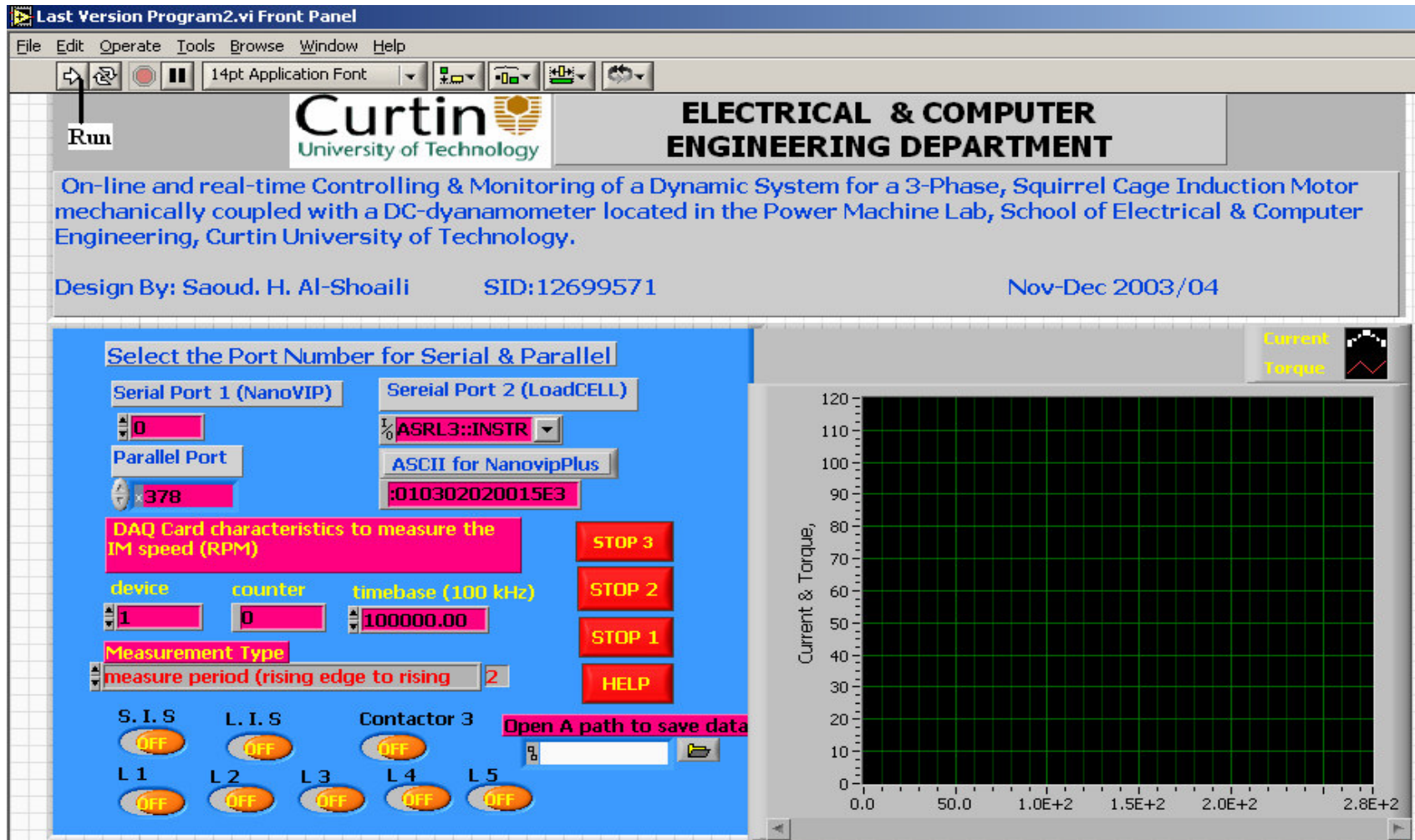
Figure 4-5 image captured from the program front panel
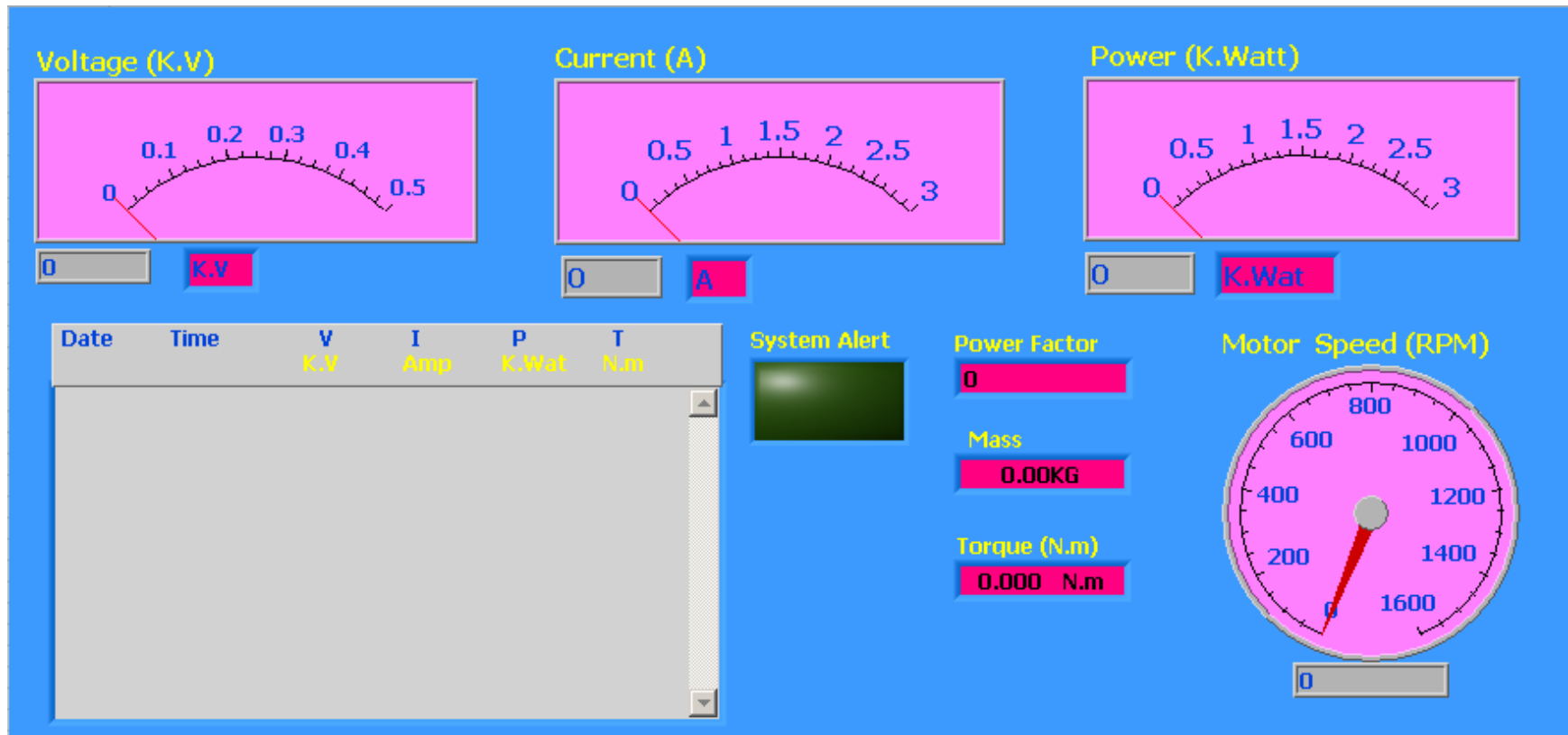
Figure 4-6 image captured from the program front panel
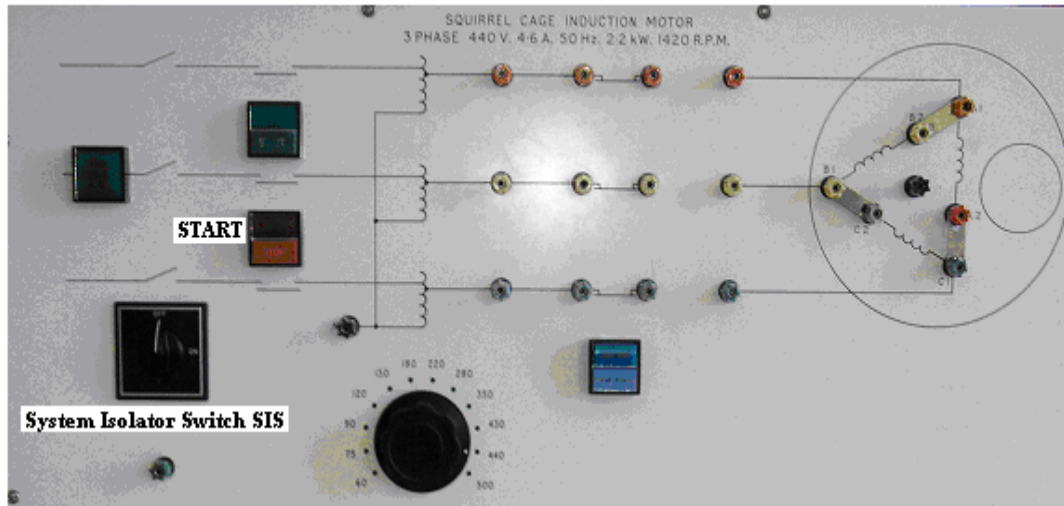
Figure 4-7 the Induction Motor front panel
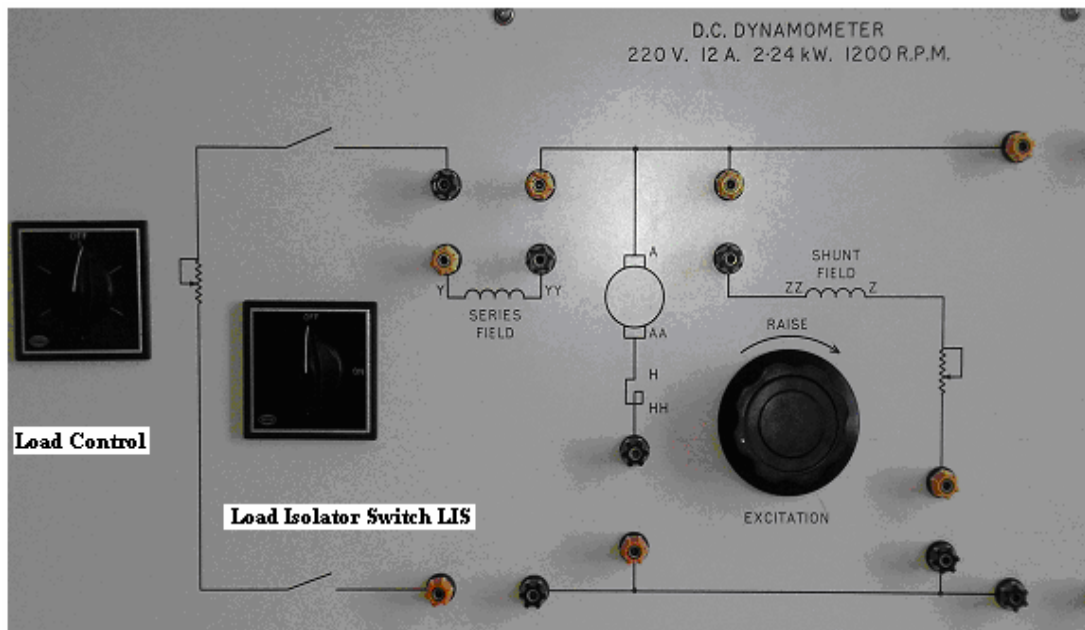
Figure 4-8 the DC-Dynamometer front panel

4.3.2 Result of the Local Monitoring and Control

As a natural result to the works that have been conducted in the previous stages of this study, the first test was carried out successfully. The local users have succeeded to perform a fully computerised real-time monitoring and controlling of the test-rig system of this study.

As the test-rig parameters are monitored and controlled by different M&T instruments, the data processing speed varies from one instrument to another and consequently the data presented on the computer could vary from the real values. That can be noticed on the table and on the graph where the different measurement data are listed so they can be compared with the real values. As an example to that, the graph plotter plots the relation between the current and the developed torque which are measured by the NANOVIP Plus and the load cell respectively. The mechanism that this program follows to plot the relationship in a graph passes through different steps and it starts by collecting the measurement data from the different M&T instrument. As the user end the data acquisition operation and stops the program; the collected data will be sent together in one bundle to the graph plotter. Due to that, the graph plotter could plot a graph of two reading of different intervals because of the data processing time taken by each individual instrument. Moreover, and especially on the graph, there are some intervals where the plotted line dropped abruptly to the zero points from its real value. These zero points represent the data losses during the communication between the local computer and the M&T instruments. The user is recommended to take the average measurement readings from the table that are considered to be more accurate and close to the real values as that is clear from the table.

The local user in the test-rig location was able to perform the test as it was planed. The collected measurement data was of the real instrumentation system and no simulation was involved. The VIs that have been designed are of real physical instruments. The front panel of the program is changing dynamically in a real-time basis. Some of the front panel images of the test-rig readings captured from the program during the run mode are as shown in Figure 4-9 and Figure 4-10.

Figure 4-9 shows four images of the system parameters reading; the power, the current, the voltage, the power factor and the system developed torque; as they appear on the virtual meters of the front panel. Each meter is incorporated with a

digital indicator to show the accurate reading. Figure 4-10 shows two images; the first is of the system parameters reading after they are all concatenated in a table format with the time and date. The second image shows the meter gauge of the IM rotation speed reading. Figure 4-11 shows the image of the graph plotter which looks as it is in a real oscilloscope. The plotter plots the relation between the current and the developed torque. In this plotter, there are two lines; bolded white line and thin red line; as they can be seen. The bolded white line stands for the current reading while the thin red line is for the system developed torque. From the graph, the lines drop to zero points abruptly and that points are where the communication between the measuring instruments, of both the current and the torque, and the computer is lost. As there was a file opened to save the measurement data, this file can be accessed by MS-Excel program as it can be seen in Figure 4-12.
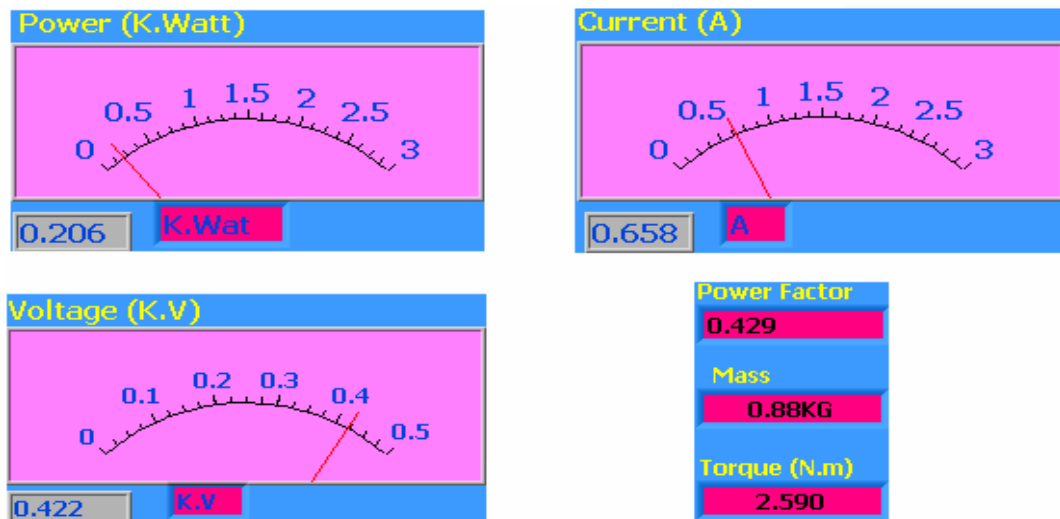
Figure 4-9 Reading meters for different parameters of the system
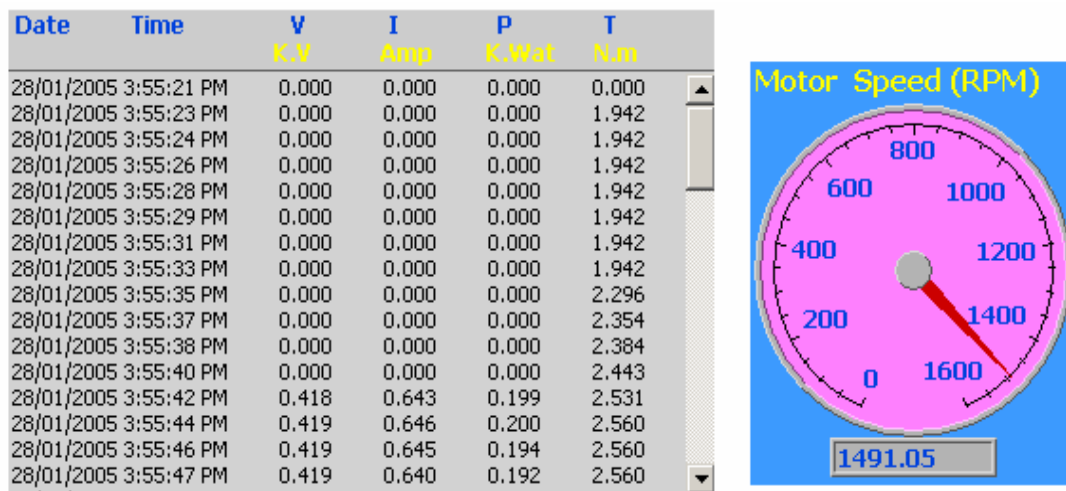
Figure 4-10 the parameters readings as they are presented on the table (left),
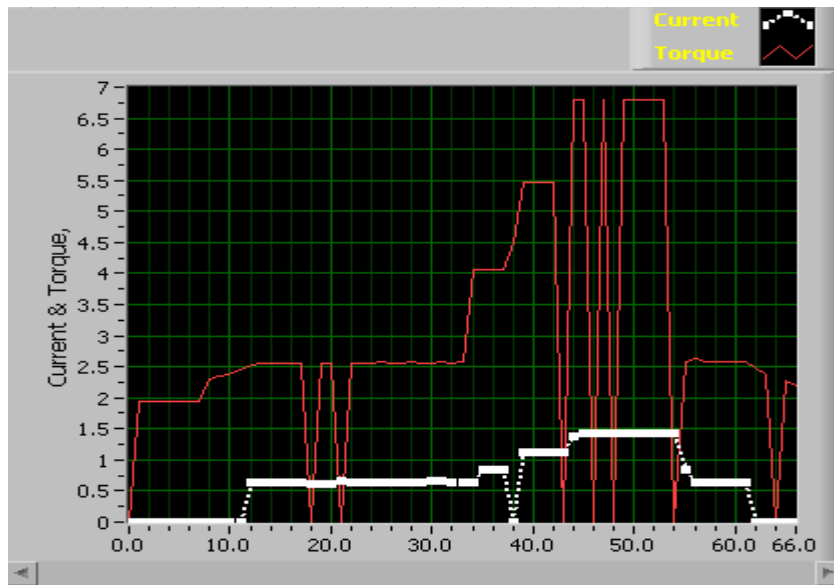
Figure 4-11 graphical representation of the relation between the torque and the current

Figure 4-12 image captured from the Excel program where the file of the

measurement readings can be opened for off-line requirements

4.4 Remote Monitoring and Control Test

4.4.1 Introduction

The second test that has been conducted on the test-rig was the remote monitoring and control operation. The first step in this test is to enable the LabVIEW remote front panel since the LabVIEW program supports the remote operation through a remote front panel [105].

The remote front panel allows users to monitor and control any VI remotely from the LabVIEW front panel or from a web browser without any programming [105]. This feature greatly expands the applications of the remote operations as an operator can run a system from anywhere and at anytime as long as an access to the communication network is provided. Besides that, several users geographically distributed can access the same VI simultaneously. Through the remote front panel, remote clients can monitor the real-time and dynamic changes of the system test-rig parameters readings on the local computer front panel as opposed to static images. The data acquisition is still occurring on the host computer (server), but the remote user (client) has total control and identical application functionality. However, to prevent the confliction between different remote users in performing remote control actions, only one client can control the front panel at a time.

4.4.2 Enabling the Remote Front Panel in LabVIEW Program

In all previous versions of the LabVIEW-based remote operation, an additional programming as third-party software tools was required to transfer the local operation functionalities to a browser environment [105]. With the continuous development and progress that have been made in LabVIEW program, today without any additional software tools, the LabVIEW program transfers the functionalities of the local operation to the remote operation through a common web browser [105]. With this new method, the user simply points the web browser to the web page address associated with the VI intended for the remote application. The client server configuration has been used in this study to facilitate the remote operation. To enable the remote front panel in LabVIEW program, some steps have to be completed to transfer the intended VI program from the local server environment to the remote client environment. These steps are as follows [105]:

1. Save the intended VI program in the LabVIEW memory of the local computer (server).

2. Select the Web Publishing Tool option from the Tools menu in the front panel. The image in Figure 4-13 will pop up.

3. The intended VI will be automatically loaded in the document title (Last Version Program2). The Document Title, Header and Footer in Figure 4-13 are all text fields that the program developer can use to customise the web page created with the publishing tool.

4. Select Save to Disk button in the left bottom corner of Figure 4-13. This will save the intended VI as an HTM file which is (Last Version Program2.htm) in this study.

5. Press Preview in Browser button to start the remote panel operation.

6. After step 5, the remote front panel will be opened in a web browser with a URL as it shown in Figure 4-14. the URL for this study is:

(http://ece-pg-206-1.eng-staff.cage.curtin.edu.au/Last%20Version%20Program2.htm)
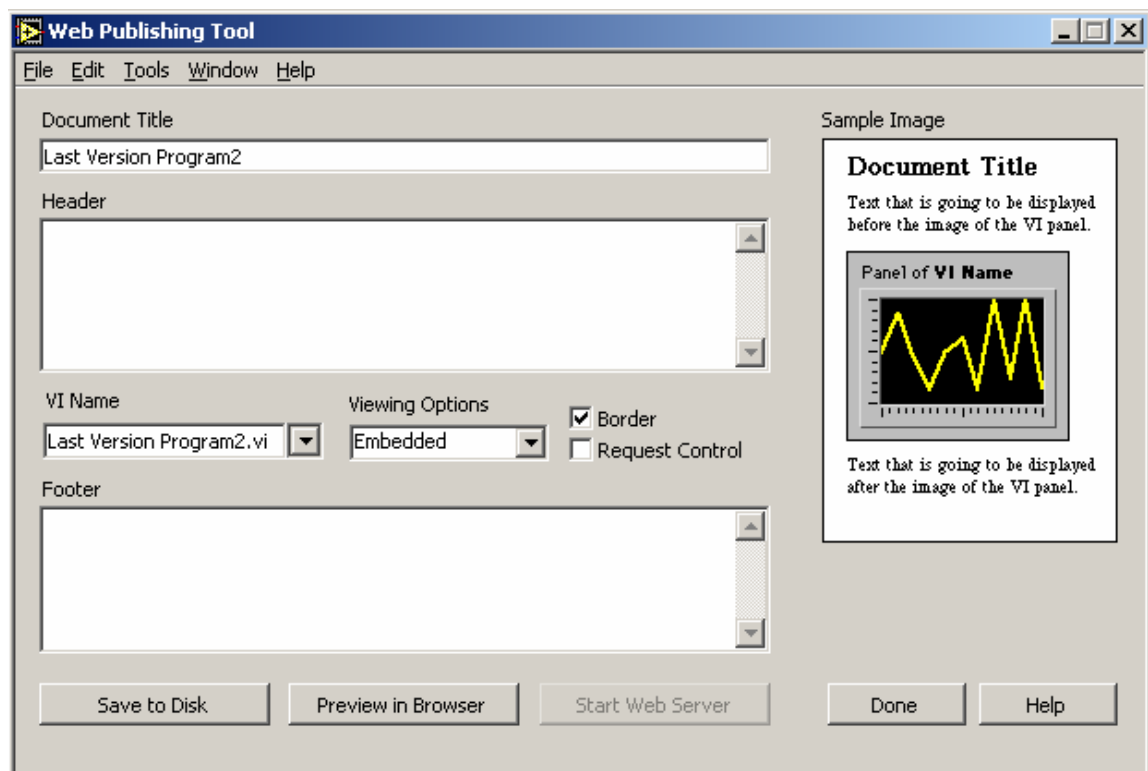
Figure 4-13 developing the remote front panel

The URL consists of two parts: the computer name (IP-address) where the program was saved, and the VI program name. As it is known in the networking field, a

4-80

remote user can get an access through the network to any computer connected to the same network by the use of the intended computer name (IP-address).

Different users who have dealt with the LabVIEW program remote front panel have experienced some errors and problems associated with the remote operation. Some of these are mentioned and listed in the LabVIEW program library, with the recommended steps to fix them, as technical supports for the users [115]. To get the best of the technical support, users are always recommended to check the LabVIEW program website for continuous updating of different errors and how to fix them [105].
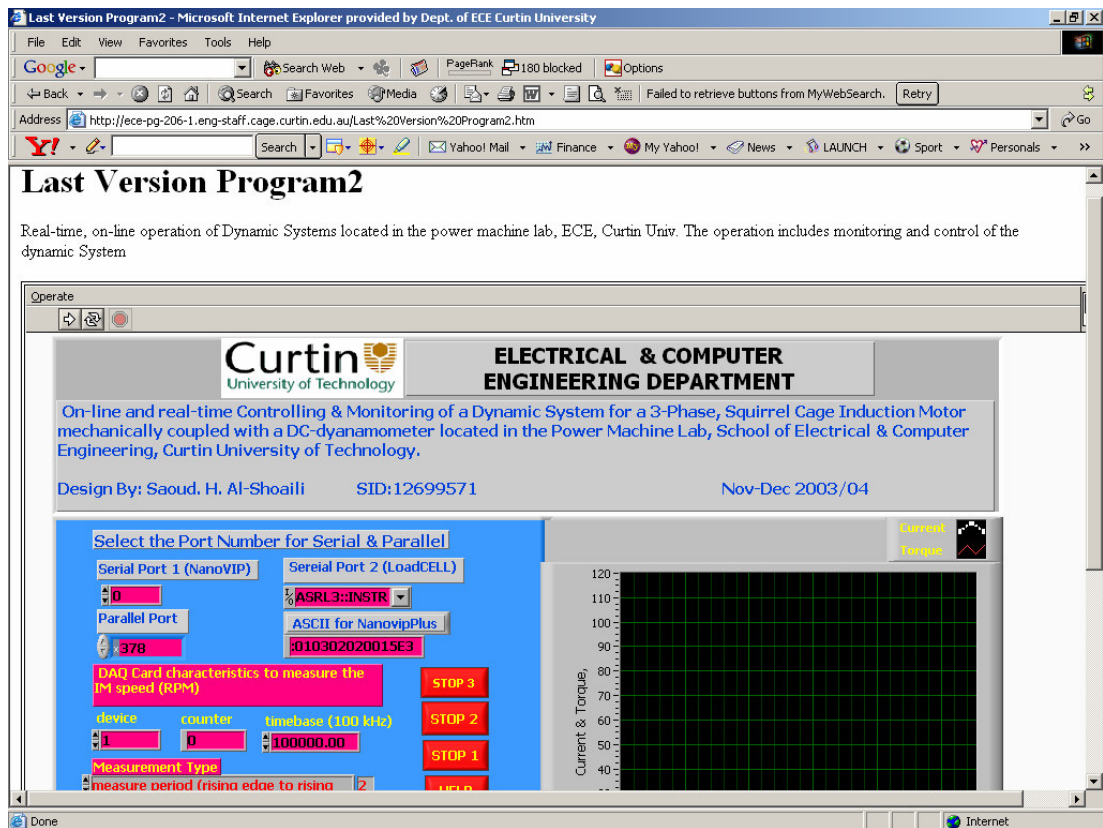
Figure 4-14 the remote front panel in a web browser through the LAN

4.5 Remote Front Panel Execution

4.5.1 Intranet-based (LAN) Remote Operation

To verify the working of the remote front panel of this study, the remote operation was carried out over the LAN of the Curtin University from different locations within the university campus. The steps mentioned in the previous section were to enable the remote front panel on a web browser. However, to operate the LabVIEW program using remote panels, it is necessary to have the LabVIEW run-time engine file installed on the client computer [105]. With this file, LabVIEW applications can be run on computers in which the LabVIEW program is not installed [105]. In addition to running the LabVIEW applications natively, the run-time engine file is also used to remotely connect to a client computer with the server computer and carry out the remote operations through the browser interface [105]. Fortunately, this file is provided by the LabVIEW program developer, NI, for free of charge. A user can log on their website and download it from this link:

http://digital.ni.com/softlib.nsf/websearch/369618104E25B08E86256F54006A4E2F?opendocument&node=132060_US. After this file being downloaded successfully on the remote computer, the remote user can monitor and control the intended VI on the server machine.

For security purposes, and to protect the system from unauthorised person access, the VI program of this study has been saved on a website in which prove of identification is required to access it. Once the user typed the URL of that web site, a username and password screen will pop up. There are some usernames and passwords have been configured for the system by the system developer and they are given for the authorised person only. If the user has that privilege, an access to the program site is granted otherwise no access can be gain and a sign of Authorization Required will appear on the screen as it is shown in Figure 4-15. Once the username and the password are provided, this website will automatically direct the remote user to the real location of the program and the user can start the remote operations.

To access the system from the remote front panel, a user has to follow these steps:

1. Ensure the test-rig apparatus are connected together as they have been described.

2. Ensure the local computer is turned ONN and the intended VI is opened.

This is because the local computer is the crossing bridge between the remote user and the test-rig.

3. Type the following URL: http://bauhaus.ece.curtin.edu.au/~shoailis on the address bar of the web browser on the remote computer.

4. Enter the provided username and the password. Upon entering these two, the remote user will be redirected to the program location on the local computer (server).

5. After the remote client was guaranteed an access, the steps mentioned on the local operation (section 4.3.1) have to be followed again.

Once the client has granted an access remotely to the front panel, the client will be automatically in a monitoring state. If another client is controlling the system, the user will be able to monitor the actions of the controlling client and monitor the dynamic change on the test-rig performance. In order to have controlling privilege, the client has to press the mouse right click on the front panel and then select Request Control from the given options [105]. Once that is selected, one of two possible messages will appear on the front panel; either the user will be granted control (Control Granted) or the user will see a message indicating that control is currently granted to another user (Waiting for control: Either the server is locked or another client has control). If another client has the control actions, the controlling client will be notified automatically by the program that control time has now become limited. Once the timeout occurs or the controlling client has released the control actions, application control is automatically transferred to the requesting client (Control Granted). After the other user has been granted control, all icons and controllers will become active on the new user panel and running the LabVIEW remote front panel application is exactly like running the applications from the local environment [105]. Due to the fact that, the LabVIEW real-time operating system comes with only one remote panel license, an extra LabVIEW real-time remote panel license file must be purchased for multiple remote panel controller [105].
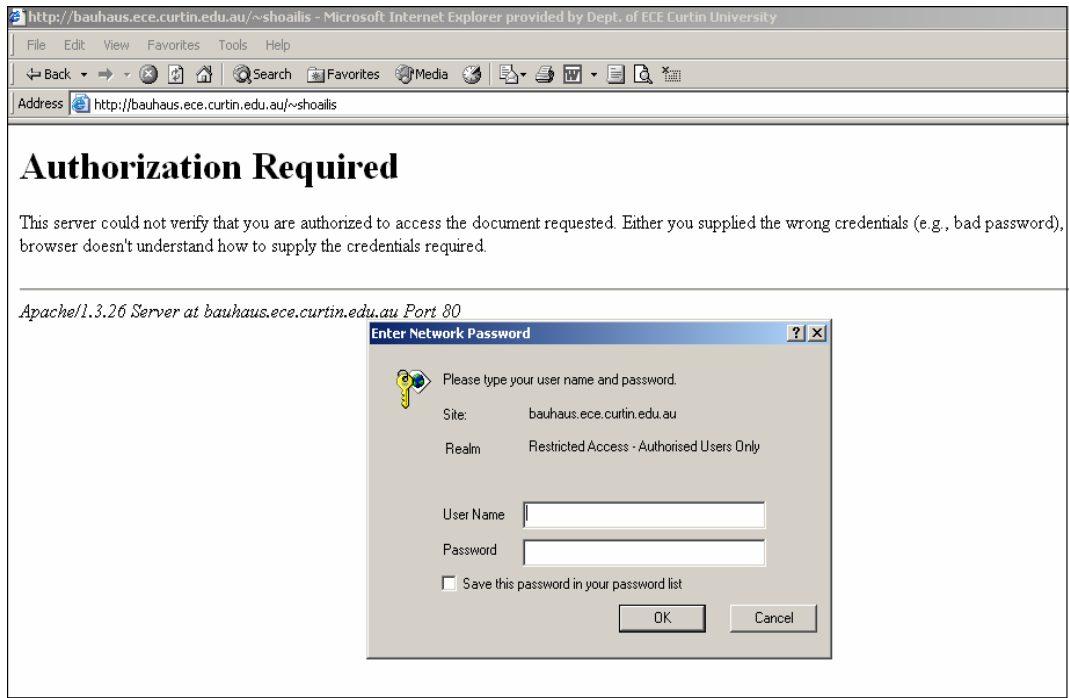
Figure 4-15 an image captured from the screen illustrate prove of identification

requirement to secure the system

4.5.2 Internet-based (WAN) Remote Operation I-bRO

Basically, there is no difference between executing the remote operation over the LAN or the WAN as the executed steps are exactly the same. The main difference is the network scale from the local area to the wide area which has positive and negative sides. Once the program is uploaded to the main internet server, it becomes opened for the general public and consequently different precautions have to be considered in order to protect the system from unplanned or unexpected operations. On the other hand, the main feature for I-bRO is that, the clients can sit anywhere on the globe, grant an access to the system and conduct the remote operations.

To ensure the program works over the WAN as it has been planned, it was tested several times from outside the university campus over the internet server. The server which was used for the testing purposes was the I-primus Telecom Company, as it is the internet service provider of the client, and the internet service is provided via the dial-up method.

One important notice worthy to be mentioned for the remote operation and it has been noticed from the program execution of this study, as the remote user is away from the server (local computer), the program is very sensitive to the commands sent from the client side. Due to that, the clients have to follow and carefully execute the

operation steps as they are ordered in their numbering sequence. It is recommended that a local operator attends the server, if possible, to fix any problems could be initiated accidentally by the remote clients. Beside that, at this stage of this program development, a remote user can not save the measurement data on the client computer if the client is not sharing the same network with the server. The data can be saved on the client computer as long as the client computer and the local computer are sharing the same network. Otherwise, a DataSocket technique can be used to save data on the client computer [115]. This feature is left for the future developments and modifications.

4.6 Comments on the LAN/WAN Remote Operation

Despite the fact that, the LAN or the WAN provides a useful communication path for the remote operations, they have some technical drawbacks. The main feature that characterised the internet based teleoperation is the time-delays and the data losses [49]. From the results of the remote operations that has been conducted in this study, the following conclusions can be drawn:

1. There is a direct relation between the computer-instrument interface method and the data transfer speed between the M&T instrument and the computer. Four different interface techniques have been used in this study; serial port, SPP, USB and the DAQ card. The fastest in data transfer was the reading taken by the DAQ device, and then the one through the SPP and the slowest was the measurement of serial-based instrument. That delays can be attributed to many reasons such as:

   - The data transmission with the serial port communication is slower than with the SPP which is slower with than the USB. Serial port for example transmits only one bit at a time in comparison to eight bits with the SPP.

   - Secondly, in the case of this study, there were two serial port-based instruments; the NANOVIP Plus& the load cell. The NANOVIP Plus measures different parameters of the test-rig. However, to present different parameter readings, NANOVIP Plus processes them individually from the main string format of the data acquired off the test-rig. The individual reading processing of the measurement data takes certain time and that time is accumulated for each parameter measurement that needs to be processed. As an example from the NANOVIP Plus, in each measurement cycles it process the voltage, the current, the power and the power factor. On contrast to other M&T instruments which monitor a single parameter of the system, the instrument process and present the reading in a faster way.

2. There is some data losses during the data transmission between the M&T instruments and the computer and that can be noticed in some cases in the table of Figure 4-12 where the parameters reading are shown zero on the

computer while they have values in the M&T instruments.

3. It was difficult for me to find the characteristics of the network server such as the transmission speed, the bandwidth or bit transmission rate and the length of the link, for both the LAN and the WAN that have been used to carry out the remote operation. These characteristics of the network have a direct influence in the system response to the control commands that are sent over the network link.

4. The number of paths for the round trip communication of the measurement data, from the system to the remote clients and back, directly affects on the end-to-end communication and leading to some time-delays. As an example to that from this study, a remote user (client) will read the actual reading of the system measurement after the reading pass through the following paths:

   - Path1: from the system to the M&T instruments.
   - Pathe2: measurement data processing time on the M&T instruments.
   - Path 3: from the M&T instruments to the local computer (server) through the interface.
   - Path 4: from the local computer to the LAN server and to the main WAN server.
   - Path 5: from the LAN or WAN server to the remote user (client).
   - The time the remote user takes till the reaction (control commands) is initiated.

In each of the above listed paths there are some time-delays and it has dynamic nature. Through the same paths the control commands will pass in the reverse direction till they reach the system to perform the necessary control actions. Therefore the total time-delays for the I-bRO are the sum of the individual time-delay in each path. The worst paths among these paths, as the time-delay is concerned, are those associated with the internet (path 4 & 5). This problem is addressed with more details in the next chapter.

Beside the above listed technical blocks, and from the two tests that have been carried out on this study, the real-time and on-line remote monitoring and control system developed has some technical limitations such as:

1. The server (local computer) has to be running the intended VI for the client

(remote user) to access it otherwise an error message will paper on the screen which is "the requested VI is not loaded".

2. There is no live image captured for the test-rig being monitored and controlled as this facility is not included in the study at this stage.

3. The server must have a multiple clients license of the LabVIEW program otherwise only a single client can control the system. Beside that the real-time engine file has to be installed on the client computer to access the remote front panel of the intended VI.

4. The file which is opened to save the test-rig measurement parameters data during the operation, which can be used as a reference or for off-line needs, can not be saved or opened from the client computer. It is saved and opened only on the server unless the client and the server share the same network drive and thus the file can be saved on the network rather than on the server drive. This can be solved by other LabVIEW techniques which are not included at this stage of this study.

5. The security that is applied in this study though, it works, is not restricting unauthersied user access. As it has been mentioned, if any user knows the IP address of the server machine and the VI file name, an access to the program can be granted from either the LAN or the WAN.

5 Internet-based Remote Operation (I-bRO)

5.1 Introduction

The continuous progress and development that have been made on the internet technology has granted the possibility of sending bundles of data or communicating with a person from one side of the globe to the other side in a very short time. The Internet-based Remote Operation (I-bRO) involves both the controlling and the monitoring of any system from a remote location. It is in which the controller or the monitor is geographically isolated from the system under control and they communicate via a communication network. I-bRO has been defined as the whole of operations performed to control or monitor a system in a closed network [130]. Control systems have assumed an increasingly important role in the development and advancement of modern civilisation and technology. It is found in almost every single aspect of home appliances, educational, industry, hospitals…etc. When it is applied, the goal of the control system is to control the output of the system (controlled variables) by adjusting the input variables (manipulated variables) with the use of a controller in order to achieve the user needs. The basic ingredients of any control system are the controlled variable of the system (system output), manipulated variable of the system (system input) and the controller in between. A real-time control system consists of sensors, actuators, controllers, data intensive devices and instrumentation to support diverse applications [131]. The block diagram structure of the basic control system is shown in Figure 5-1.
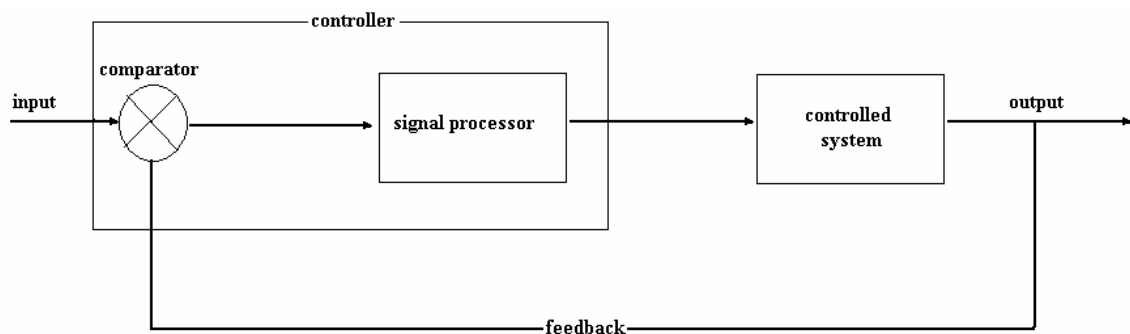
Figure 5-1 block diagram of the basic closed loop control system design

There are two types of the control system; open loop control system and closed loop control system. The difference in between is that, in the closed loop control system the control action being applied to the system is continuously modified and

updated by comparing the achieved system output with the user set points. It means the system returns the achieved output through the feedback path to the controller. This scenario does not happen with the open loop control system. In these two types of control, the control system can be either manual or automatic. Most of the modern control systems are fully computerised in which a single or multi computer stations monitor and control the system. The human interfere happens only in the emergency cases or to reset or modify the system performance. The main feature of the computer-based control system that it can be used for on-line and off-line analysis [112].

In the basic control system design, wether manual or automatic, the controller and the controlled system are interacting directly with each other without any media in between. However, the controller and the control system could be physically isolated from each other. The new generation of the control system is the large scale and network-based control system. The networking can be done over a small-scale network as the intranet (LAN) or over a large-scale network as the internet (WAN). Throughout this chapter, the I-bRO is studied. The main philosophy behind the I-bRO is to grant users the possibility to access remote systems through the internet from anywhere and at anytime. The internet adds an advance level to the modern computer-based control system by incorporating the internet in the control hierarchy and globalising the communication link between the field instruments and the user.

The I-bRO has been successfully applied to enhance the research and development process of different fields such as in education, medicine and process control. The block diagram or the basic structure of the I-bRO is shown in Figure 5-3. The I-bRO terminals that are directly subjected to the internet link are the field M&T instruments (such as the sensors, transducers and actuators) and the controller, as the tasks performed by these elements is transmitted to the system over the internet. The sensors and transducers measure the system output values and feed these back to the controller over the internet. The controllers read the system output values, which are feedback by the M&T instruments, process them by the use of the control theories and issues the necessary control commands to the system through the internet. The actuators receive the new control commands, as the system inputs, from the controller over the internet and apply these commands on the system.

The first step in globalising the control system and performing the I-bRO is to upload the control system to the internet server. That can be done through two

different methods as the literature showed [48]. The design task of the I-bRO is complex in comparison with the computer-based control system and involves both hardware and software considerations. In the I-bRO design, the internet or intranet can be added to the control system hierarchy at any of three different levels; the regulatory level, supervisory level or at the optimisation level as it shown in Figure 5-2 [49]. However, the addition of the internet to any of these levels has both advantages and disadvantages and the designers have to compromise between them. When a control system is implemented in a networked fashion with multiple processors communicating over a network, both the communication delays associated with the network and the computation delays associated with the processing time can degrade the performance of the system [49]. In this case, the performance of the entire control system may depend not only on the performance of the individual components of the system but also on their interaction and cooperation [49].
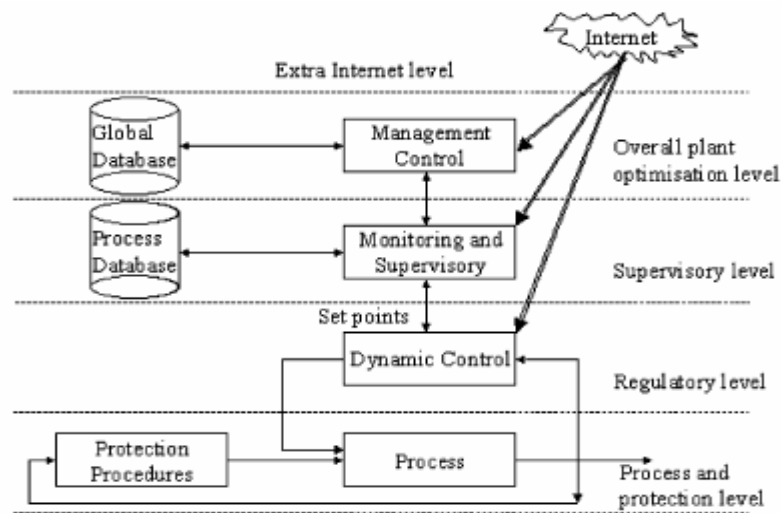
Figure 5-2 Process control system hierarchy and possible links with the Internet [49] Yang *et al*, 2003] .
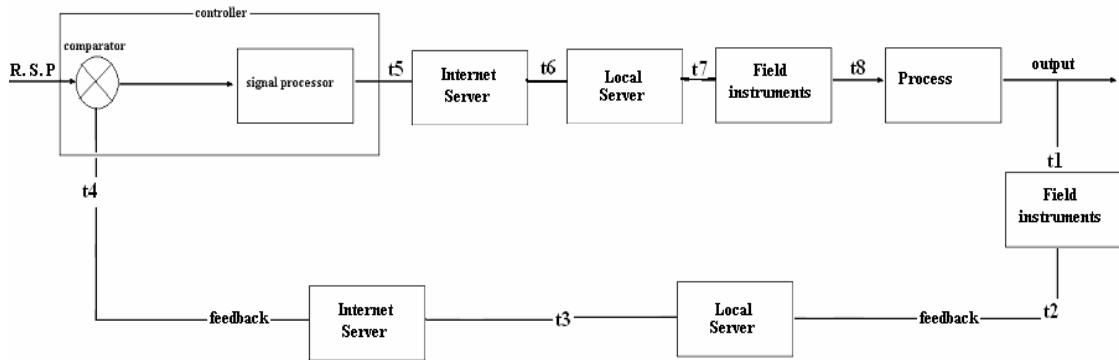
Figure 5-3 the basic structure of the I-bRO

The literature showed two methods have been used to design the I-bRO. One of the design methods is based on the interfacing the devices and the instruments of the controlled system to a local computer which in turn is connected to the LAN which is a node on the WAN server. In this design, the local computer acts as a server to the system and implements the remote user commands on the system. The other design method of the I-bRO is more advanced in which the devices and instruments of the controlled system are connected directly to the intranet or internet server as they are provided with this facility. There are few companies try and the other some succusseded in producing the control instruments and devices with built in internet connection capability [49], [58]. Recently there are new ranges of controllers and instruments that can serve the web pages over either LAN or the WAN [48].

However, in both design methods, the internet remains the media for the data communication between the system and the controller. The differences and similarities between these two different designs has been studied [48]. The first design, in which the control system devices and M&T instruments are interfaced with a local computer, has been applied in the development of the I-bRO for the test-rig studied in this research. It has been also used by several researchers and developers [112], [53], [60] and [58].

5.2 Literature Survey

The continuous development in communication and networking modify the feature of information exchange. The growth of the internet is accompanied by the increase of its applications. The use of the internet for remote monitoring and control applications is exciting due to its ubiquity, cost and standardisation of equipment and communication protocols [132].

In the last few years, there have been much interest in the control research community to implement an Internet-based Remote Control (I-bRC) of a physical plants and several models have been developed [133]. The continuous development and progress in networking and hardware speed has enhanced the research in the field of real-time control over the internet [90]. For several years, members of the Institute of Electrical Information Technology (IEIT) have been working on monitoring and controlling remote system using internet [134]. Because of that, different strategies and methods have been developed for the I-bRO on different systems. Recently many new internet-based applications known as teleoperation have been introduced [135]. For the teleoperation applications, the internet provides a cheap and readily available communication channel [53]. Since 1980, when the Cambridge Coffeepot at Cambridge University appeared as a first device controlled over the internet, researchers have put great efforts to integrate the internet for the remote control or monitoring purposes [53]. The Cambridge project had a text-based internet interface to soda machines and had the first internet camera which was set up by researchers to monitor the status of the coffeepot [53]. The first contribution to two international projects on the I-bRO and teleoperation was the remote control laboratory which was known as SelfLab@Home of the department of Electrical and Computer Engineering at the University of Calgary [136]. This project has covered two aspects of the I-bRO; the software and the hardware. The software concerns on the internet application to control remote devices while the hardware concerns on the real-time instrumentation for the teleoperation. The first system that has allowed the web users to remotely view and alter the real world was the Mercury project, released in September 1994 [53]. The project consisted of an industrial robot arm with a camera and a pneumatic system allowing users to pick up and manipulates various objects in a sandbox filled with buried artifacts in the robot workspace. Internet-based water level control of a tank has been studied at the University Tenaga

Nasional [60]. Methodology for remote operation and monitoring of plant components through the internet and the web technology has been performed at Fort Valley State University [58]. The test-bed for that study was a motor-generator station and the authors concluded that the I-bRO can be applied to a plant components and process with some modifications. Researchers at Arizona State University have succeeded to perform remote control & visualisation and in bringing the Scanning Probe Microscope (SPM) live data available on the web [61]. A prototype Web-based Controlling System (WCS) that could serve as a remote control tool for an unmanned manufacturing cell in an educational laboratory has been developed [88]. The first telerobotics project developed in Australia was at the University of Western Australia in Perth [56]. In this project, users are allowed to control, remotely, the robot arm by supplying the desired X,Y,Z positions to the server in a HTML form. The server will capture and transmit monochrome images of the robot to the user, only at the end of each move.

Internet-based Process Control (I-bPC) is relatively a new concept and has received much attention in the previous years. It has a bright future, especially in the companies with many branches where the production fields are geographically distributed. Despite the wide use of the internet in the field of the information technology, it is still a new concept in the field of process monitoring and controlling [58]. In the last few years, there are many efforts and laboratory experiments have been carried out with an intention to investigate and practice the I-bRO of the process plants. There are many issues raised as a result of introducing the internet in the process control hierarchy and these issues have to be seriously considered during the system design as they influence on the entire system performance. These issues such as the web related traffic delays, the web-based interfaces, the uncertainty about who the users are, the concurrent user access and the web-related safety and security [49]. These issues have made the design methodology for I-bPC systems different from those for computer-based process control systems [49]. Recently there have been many discussions between the researchers in the field of the I-bPC if a closed loop and continuous remote control of a process plant is possible. Monitoring a process plant over the internet is feasible since there are different types of controllers and M&T instruments that are either LAN or internet enabled. However, that requires a high speed network while the traditional communication protocol, TCP/IP, assures data delivering but does not guarantee transmission deadline [137]. Unlikely

to the Internet-based Remote Monitoring (I-bRM); the Internet-based Remote Control (I-bRC) requires deep study and investigation as the internet environment is affected by different factors that degrade its quality to act as a link between the process and the controller [76]. The possibility of achieving a real-time and continuous feedback control system by using computers at remote locations and networked with the system by the internet have been studied [75]. It has been found, the continuous control of a real-time system in the internet environment is possible but not yet possible to configure long lasting stable feedback control systems. The author suggested further studies to reduce the time-delays in the internet environment. The difficulty in achieving continuous control system over the internet is attributed to the nature of the time-delays over the internet as it is variable and unpredictable beside the modelling of this time-delays is unreasonable [125]. Some researchers think that, the I-bRC for a process plant should be restricted in applications to the parameters that are controllable and achievable through the internet and the parameters that are time deterministic should be avoided [49]. They thought of that because today's internet provides no real time delivery guarantees and have essentially unbounded end-to-end latency [131]. On the other hand, some researchers think the time-delays associated with the network do not affect on most of the industrial process plants because of their sluggish nature [90].

Nowadays, the internet service is provided to the users from different vendors through different techniques. Some of these techniques are the dial-up connection, which is the most publicly used, DSL, ISDN, HDSL and cable modem. Most homes are getting the internet service through a dial-up modem with 28.5kbps to a maximum of 56kbps upstream speed, which does not have the potential for the real-time applications at the required bandwidth [64]. A comparison on the quality of the service including the communication speed, reliability, security, flexibility and the prices between all these techniques has been made and it can be revised in the appendix section [138]. Furthermore, a comparison between the control system requirements and the capability of the current internet service has been made and the result is shown in Table 5-1 [131]. From the table, it is clear that today internet is not ready to be applied for the real-time applications in process plants where the time-delay is crucial to the controlled system. Some more development in the internet server speed is required and once that happened, it will redefine the way the people use the internet technology. As it has been shown in that comparison, each method is

different from the other in term of the time-delays encountered in the communication loop. Each of these methods can be applied in different applications depending on how importance is the time-delays to the controlled system.

Control system requirements	Current internet capability
Reliable, sustained throughput of 10Mbps. For example, state-of-the-art is switched Ethernet for control.	Unreliable, widely variable throughput depending on traffic conditions. Just beginning to see traffic engineering for guaranteed QoS.
Secure network protected from malicious attacks.	Limited, at best. Still a research issue.
Reliable multicast for coordination and synchronisation.	Experimental stage.
Predictable bounded latency.	Unpredictable latency. ((US) coast-to-coast 100ms +).

Table 5-1 Current Control System Requirements vs. Current Internet Capability

The literature has shown there is a wide trend to the application of the I-bCS applications especially for the industries. The researchers and developers work hard to solve the major problems initiated from the incorporation of the internet with the control system.

In this study, the remote operation, including both the monitoring and controlling, of the dynamic system has been investigated. The dynamic system in this study is a station of an Induction Motor (IM) which is mechanically coupled with a DC-Dynamometer. The factors associated with the internet especially the time-delays have been deeply investigated and simulated.

5.3 Characteristics of the I-bRO

One of the main fields for the application of the I-bRO is in the industrial plant process control. The main idea behind the I-bPC is to enhance rather than to replace the popular computer based process control [49]. However, the design methodologies used for the computer-based control system are not appropriate to be used and applied for the I-bRO as the previous design does not consider the inherent characteristics of the internet [49]. There are many advantages that have been added to the control system as a result of incorporating the intranet or the internet in the control system design. The most dominant features of the system with a common communication network, the internet in this case, is the reduction of the cost of the field cabling, the modularity and the flexibility in system design [139]. I-bRO grants the possibility of having the system under concern in hazardous areas and remote locations while the controller or the person on duty can sit in a more comfortable environment. Furthermore, it will enable the use of expertise and infrastructure available elsewhere and creating revolutionary advanced control applications such as control on-demand, just-in-time maintenance and remote operation [131].

Despite these advantages among others of the I-bRO, there are some technical drawbacks associated with this new paradigm. Exposing the control system to a large-scale and open network such as the internet has the risk of undesired consequences. Due to that, the I-bRO requires more thought in the design and the implementation, since the internet is influenced by many factors such as the number of nodes, the internet loads, time-delay, the processing speed of nodes, the connection bandwidth, the amount of data and the transmission speed [125]. The great disadvantage of the I-bRO is the variable and random time-delays beside the data lost throughout the communication.

In the process control field, the time-delay is defined as the time the process takes since the moment the controller makes a change in the control signal until a reaction is seen on the output variable of the process [140]. The currently used internet provides no real-time delivery guarantees and have essentially unlimited end-to-end latency [131]. The end-to-end communications delays in a control system cycle can be classified into four major components: the control commands generation delays, the commands queuing delays, commands transmission delays, and delivery delays [141]. These different delays degrade the performance of the entire control system

and make it looses its stability as a large internet time-delays make some control inputs distorted [125]. It is been long since the researchers have realised that the existence of the time-delays in the communication link between the local and the remote zone is one of the added important problems regarding the stability of teleoperation systems [142].

From the classical control theories, it is possible to conclude that a delay in the control loop is an important factor causing the system instability as it increases the phase shift between the input and the output signals of the control system and thus limits the maximum allowable gain [142], [143]. This occurs because the poles of the Closed Loop Transfer Function (CLTF) of the system will start, as a result of the time-delays, to move into the Right Half Side (RHS) of the S-plane and thus the system become unstable [106]. Moreover, as there are time-delays in the control loop, any disturbance entering the process will not be detected until after a significant period. Therefore a time-delay compensation of the control loop appears to be attractive since it could improve the robustness and possibly increase the performance of the closed loop control system [143]. In the teleoperation, 0.5 seconds or more of time-delays are considered to be significant problem for the human operator and the ideal strategy for this case is to apply the move-and-wait approach [144].

I-bRO different from the traditional remote control in several aspects as follows [53]:

1. Time-delays with the internet-based operation are high and unpredictable unlike to the traditional remote operation where the time-delays are known and can be determined.

2. Internet-based operations require high degree of tolerance to compensate for the data losses during the transmission.

3. Internet-based operations are designed to handle multiple users over a single object. The users have no idea about each other so a mechanism is required to organise the multi-clients operation. Although the traditional remote control handle multi-clients operation, but mostly they are close to each other and it is easily for them to coordinate between each other.

4. The internet operation is open to any person connected to the internet, which is unlike to the traditional remote operation. This issue has to be addressed as it affects the entire control system security. Hackers continuously invent new

methods to penetrate different systems on the internet.

From Figure 5-3, the total time-delays for the round trip of a single control cycle in the I-bRO (from the remote controller to the system and back) is possible to be analysed as follows:

1. t1: Measurement time. The communication time between the process and the field M&T instruments.

2. t2: Interface stage time. The communication time between the field M&T instruments and the local computer (server).

3. t3: The communication time between the local server and the internet server.

4. t4: The communication time between the internet server and the remote controller.

T5, t6, t7 and t8 are the time-delays of the control reverse cycle from the remote controller back to the process as it is shown in Figure 5-3. There are two more time-delays are not shown or mentioned in the block diagram of Figure 5-3. These delays represent the computational time (measurement data processing) and the response time the controller takes till it issues the required control actions based on the feedback data. As the controller type in the test-rig of this study is a human-based and manual controller, the time-delays will vary from one user to another depending on how fast or slow the users respond to the system. The total time-delays for the round trip control cycle are the sum of these individual delays listed above. From this analysis it can be concluded the followings:

1. t1, t2 and t7, t8 are the time-delays between the test-rig and the local computer in both direction; forward and feedback. These time-delays are assumed to have constant values thus they can be measured and improved since they mostly rely on the local computer processor speed and its performance. It has been found that, the server Central Processing Unit (CPU) speed is the most important factor for determining if a successful remotely operated measurement system can be implemented [57]. As CPU clock speed increases, the delay decreased significantly and visa versa [57]. Beside the server CPU speed, the number of layers of software at the instrument location was found as a factor affecting on the performance of remote operation [57].

2. T3, t4, t5 and t6 are the time-delays associated with the network (LAN or WAN) server. These time-delays affect on the entire server performance and

they are dynamic, random and unpredictable.

The above analysis shows two types of the time-delays incorporated with the I-bRO; the delays associated with the communication network and the time-delays associated with the test-rig elements such as the M&T instruments and the control devices. The second type can be modified and improved as it is mainly related to the devices and the M&T instruments used on the system.

To overcome the problems associated with the internet time-delays throughout the control cycle, different methods and designs have been applied so far to improve the performance and to enhance the stability of the control system at the presence of the time-delays. The foremost method introduced to eliminate the effect of the time-delays on the control system was by using a time-delay buffers [45]. It has been found if the buffer is chosen to be larger enough than the worst case of the communication time-delays, it would be possible to determine the time delay for the data transfer between two nodes and thus eliminate its affect on the control system [139]. The negative side associated with the buffer introduction in the control loop is the possibility of using an older information than what is really needed to be used for the control purpose [139]. Furthermore, the buffers can lead to a degradation of the entire control system performance [139]. Some researchers have studied the random time-delays, which is the case with the internet time-delays and model it by the use of the Markov chains, with the subsequent delays dependent on the preceding delays [54]. Another method that has been used to eliminate the time-delays affect on the control system was by determining the internet time-delays experimentally and then analyse the affection of the delays on the control system [45]. In this method, the internet time-delay was measured by the use of the Packet Internet Groper (PING) utility at different dates and different times of the week. From the measurement results of using the PING utility, a lead-lag compensator has been designed to compensate for the total time-delays [45]. Similar method has been applied in which the transmission efficiency of the internet was repeatedly tested by sending data each time from a fixed web browser to different remote browsers [49]. The result showed that the latency of the internet contains uncertain time-delays.

A new method called a Virtual Supervision Parameter Control (VSPC), which is insensitive to the internet time-delays, has been implemented [49]. In this method, two controllers have been used in the control loop; a local controller and a remote controller. The remote controller is the VSPC and it is invoked only to update some

parameters of the local controller such as the set points otherwise the local controller controls the process. Adaptive control system in which the system varies its parameters automatically with the unexpected internet time-delays is another method which has been applied to minimise the effect of the time-delays on the system performance [145, 146]. Smith predictor for dynamic time access delays in LAN based control system has been suggested [147]. Smith predictor has the potential to improve the control system performance significantly [143]. It allows the controller to predict the future effect of its present efforts and to react promptly to these predictions. [143]. An equation has been derived and developed to calculate the time-delays associated with the internet path (t3, t4, t5, t6) at instant k as follow [49]:

$$T_d(k) = \sum_{i=0}^{n} \left[\frac{l_i}{C} + t_i^R + t_i^l(k) + \frac{M}{b_i} \right]$$

$$T_d(k) = \sum_{i=0}^{n} \left(\frac{l_i}{C} + t_i^R + \frac{M}{b_i} \right) + \sum_{i=0}^{n} t_i^l(k)$$

$$T_d(k) = \qquad d_N \qquad + \quad d_L(k)$$

<div align="center">Equation 5-1 Internet time-delays calculation</div>

Where:

l_i: the ith length of link. C: the speed of light.

t_i^R : The routing speed of the ith node. $t_i^l(k)$: The delay caused by the ith node's load. M: the amount of data. b_i: the bandwidth of the ith link..

d_N : A term which is time-independent. $d_L(k)$: A time-dependent term.

At a glance to this Equation, it contains two terms, time-independent term and time-dependent term. As there is a time dependent term ($d_l(k)$), it is somewhat impractical to model the internet time-delays for accurate prediction at every instant [125].

Despite all these efforts that have been made to minimise the effect of the time-delays on the I-bRO performance, another study has shown that the telecommunication delays over the internet do not affect the control performance of most chemical processes due to their sluggish dynamics [90]. Due to the previously discussed problems associated with the internet, the focus in the development and practice of the I-bRO will be toward the I-bRM until the problems related to the internet server are solved then the I-bRC will be widely opened [130].

5.4 The Test-Rig Characteristics

The test-rig that has been selected for this study stands for a continuous data acquisition and control of a dynamic process plant. The IM and the load represent the process, different M&T instruments stand for the field elements and the local computer represents the process controller. The test-rig control system block diagram with the local control is shown in Figure 5-4. It is a standard closed loop control system and the control commands are issued and implemented manually.
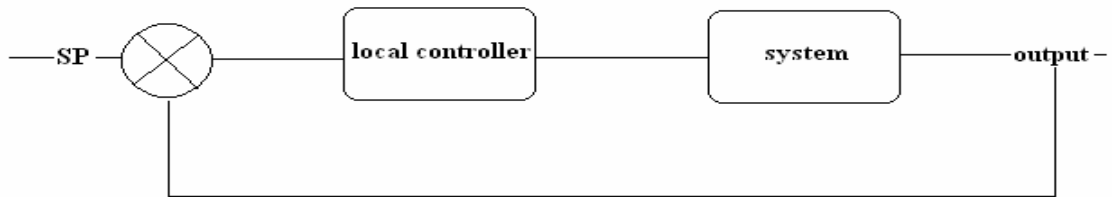
Figure 5-4 block diagram of the test-rig local control system

After uploading the system to the network and developing the I-bCS, the network will be incorporated in the block diagram in the both paths; the forward and backward as it is shown in Figure 5-5. The local controller in both paths; the forward and backward represents the local computer (server) while the M&T instruments that are located between the local controller and the test-rig, are not shown in this diagram.
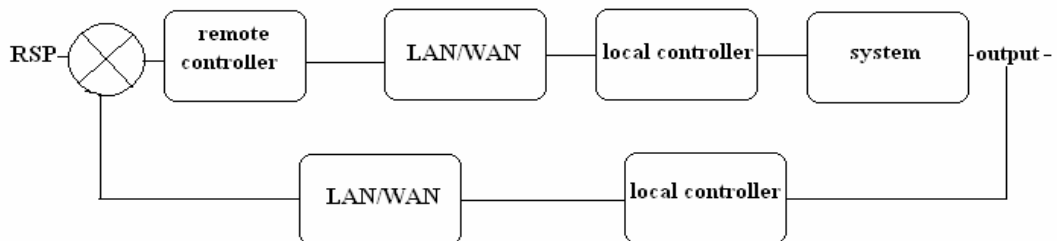
Figure 5-5 test-rig block diagram for the I-bRC

5.5 Analysing the I-bRO

The utilisation of a public server network with random demands such as the internet, produces delays in the control loop from the controller to the process, and from the process back to the controller throughout the I-bRO. These delays take a random fashion and it could deteriorate the control system performance as well as the control system stability [130].

The block diagram of the I-bRO can be simplified drawn as it is shown in Figure 5-7.
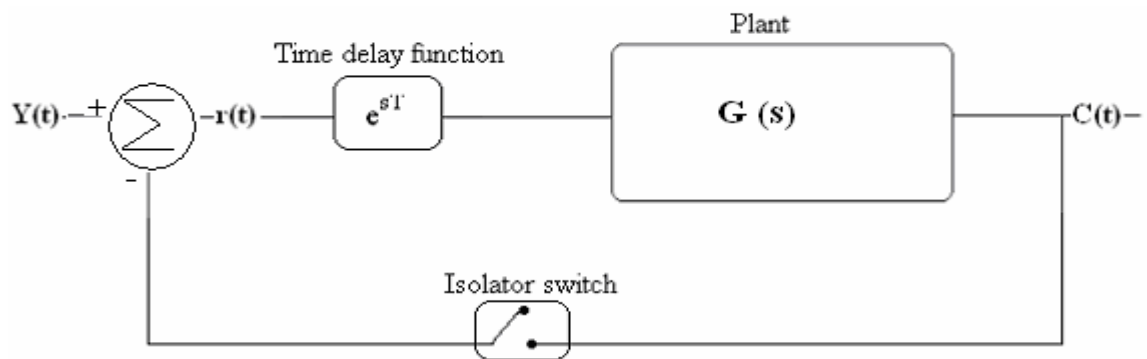
Figure 5-6 simplified block diagram of the I-bRO

Figure 5-6 illustrates a simplified block diagram of the I-bRO. The control elements such as the M&T instruments and the local controller are not shown in this diagram as they do not cause the major problems during the I-bRO. This block diagram contains three different elements as follows:

1. The system (plant). The system used in this study is a second order system (motor or generator) and thus a second order transfer function has been used for analysing the I-bRO.

2. The time-delays function block.

3. Isolator switch represents the internet server. The server either is connected so the switch is closed or the server is disconnected and so the switch is opened.

Throughout the internet operation, the operator or the controller can not anticipate the delays in the communication or the total server disconnection with the system as that relies on other different factors. In the worst cases, the internet server will totally cut off and thus the communication between the controller and the system will disappear. In this case the system is treated as an open loop control system. Based on

this analysis, the I-bRO will have two different states:

1. ***State1.*** Closed loop system with random and different time-delays.
2. ***State2.*** Open loop system when the internet server is cut off.

However, the system does not change between these two states (closed loop system with random time-delay and open loop system) in a constant manner. Instead it jumps randomly between them.

To study and analyse the I-bRO characteristics in the above two states for the dynamic system, it will be studied from the load side or from the DC-Dynamometer side of the test-rig. However, as the motor and the generator are opposite to each other in the energy conversion, the motor will be used for the analyzing purposes. The investigation and the simulation of the system will involve the followings:

1. Derive the dc-motor transfer function.
2. Module and approximate the internet time-delays.
3. Derive the Closed Loop Transfer Function (CLTF) for different values of the time-delays.
4. Simulate the system response for all values of the time-delays in both states.

5.5.1 The DC-Motor Transfer Function

The dc-motor transfer function has been already derived and it was found to be a second order system. The input to the motor is the rated voltage and the output is the rotational speed. The CLTF of the motor has been found to be [148]:

$$\frac{\omega_M(s)}{V_M(s)} = \frac{\dfrac{K_M}{L_A J_M}}{s^2 + S\left(\dfrac{R_A}{L_A} + \dfrac{B_M}{J_M}\right) + \dfrac{R_A B_M + K^2{}_M}{L_A J_M}}$$

Equation 5-2 dc-motor transfer function [148]

Where:

1. ω_M : The rotational speed.
2. V_M: The input voltage
3. K_M: the motor constant
4. L_A: Armature inductance
5. J_M: Motor inertia.
6. R_A: Armature resistance
7. B_M: Motor damping
8. T_M: developed torque.

The above parameters for the motor under study have been given the following values [148]:

1. $K_M = 1.14$
2. $L_A = 14.9\text{mH}$
3. $J_M = 0.1\text{kg m}^2/\text{sec}$
4. $R_A = 1.671$ ohm
5. $B_M = 0.0051$ kg m/sec

As the motor is an electromechanical system, it has two types of energy conversion; electrical and mechanical. Therefore the CLTF in Equation 5-2 has been derived through different steps following to the energy conversion until it comes in that form. These steps are shown in the following figures:
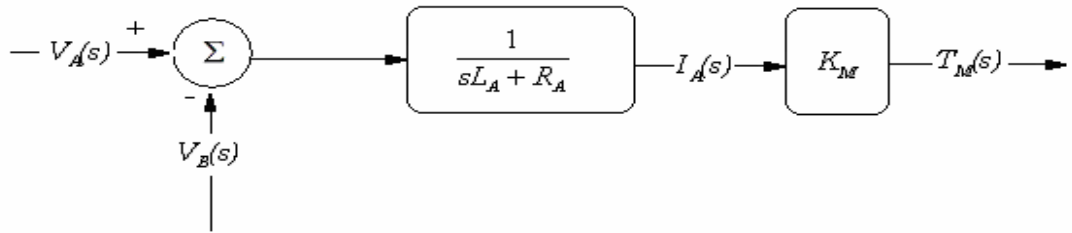
Figure 5-7 electrical energy part of the dc-motor
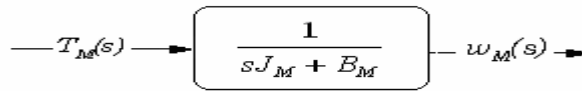
Figure 5-8 mechanical energy part of the dc-motor

By combining the two parts; the electrical and the mechanical, the following closed loop dc-motor block diagram shown in Figure 5-9 is constructed.
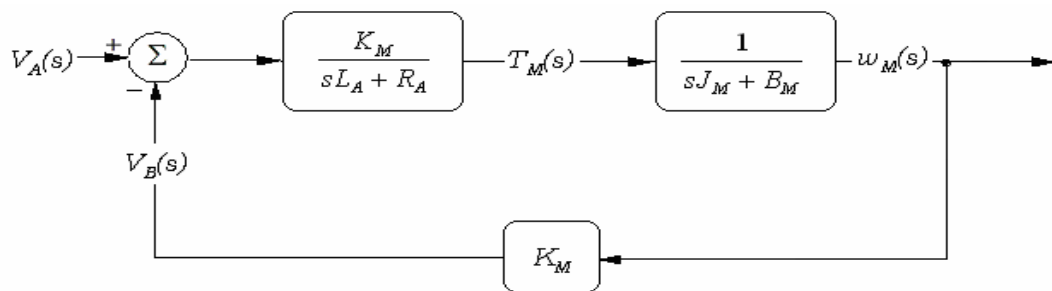
Figure 5-9 dc-motor, no-load block diagram

If the transfer function in Equation 5-1 is compared with the general second order transfer function, the followings can be drawn:

1. The motor natural frequency,

$$\omega_n = \sqrt{\frac{R_A B_M + K^2{}_M}{L_A J_M}}$$

Equation 5-3 motor natural frequency

2. The motor damping ratio,

$$\zeta = \frac{(\frac{R_A}{L_A} + \frac{B_M}{J_M})}{2\omega_n}$$

Equation 5-4 motor damping ratio

In order to study and analyse the generator response in the control loop with the random time-delays, the later has to be approximate and lineralised. This is explained in details in the next section.

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5.5.2 Approximating the Random Time-Delays

The time-delay or the dead-time is represented in the control system by an exponential function e^{sT} which is a nonlinear transfer function. As most of the control design methods require linear systems, this function has to be lineralised in order to analyse the control system in the presence of the time-delays [149]. The literature has shown some methods that have been developed to approximate this function and thus lineralise it. The most widely used method among those is the Pade approximation [150]. The other common methods of the time-delays approximation are the Taylor Series and the Low Pass Filter (LPF) [151].

The second order approximation of the time-delays in these three methods has been found to be as follows [149]:

1. Pade approximation

$$e^{sT} = \frac{T^2 S^2 - 6TS + 12}{T^2 S^2 + 6TS + 12}$$

Equation 5-5 time-delay approximation with the Pade method

2. Taylor Series approximation

$$e^{sT} = T^2 S^2 - 2TS + 2$$

Equation 5-6 time-delay approximation with the Taylor series method

3. LPF approximation

$$e^{sT} = \frac{2}{T^2 S^2 + 2TS + 2}$$

Equation 5-7 time-delay approximation with the LPF method

Where T in the above equations denotes to the random time-delays in the control loop. The approximation method used in this study is the Pade approximation method. After approximating the time-delays function, it would be much easier to analyse the system under the two states:

1. State1. Closed loop system with random and different time-delays.

2. State2. Open loop system when the server is cut off.

This is carried out in the next section.

5.6 State1 Closed Loop Control with Random Time-Delays

This is the first state to be analysed for this system. In this state the internet server switch is assumed to be closed all the time. However, the communication is subjected to random time-delays. As it can be seen in the Equations 5(5-7), the time-delay approximation transfer function has a dynamic nature as the time-delay is. Therefore, for each value of T, the approximated transfer function takes different characteristics and so does the entire system. As an example to that with the Pade approximation for different values of T, the approximated time-delays transfer functions for 1s, 1.5s, 2.5s, 4s, 5.5s and 6s will be as follow:

$$e^{sT} = \frac{s^2 - 6\,s + 12}{s^2 + 6\,s + 12}$$

Equation 5-8 Pade approximation for 1s time-delay

$$e^{sT} = \frac{2.25\,s^2 - 9\,s + 12}{2.25\,s^2 + 9\,s + 12}$$

Equation 5-9 Pade approximation for 1.5s time-delay

$$e^{sT} = \frac{6.25\,s^2 - 15\,s + 12}{6.25\,s^2 + 15\,s + 12}$$

Equation 5-10 Pade approximation for 2.5s time-delay

$$e^{sT} = \frac{16\,s^2 - 24\,s + 12}{16\,s^2 + 24\,s + 12}$$

Equation 5-11 Pade approximation for 4s time-delay

$$e^{sT} = \frac{30.25\,s^2 - 30\,s + 12}{30.25\,s^2 + 30\,s + 12}$$

Equation 5-12 Pade approximation for 5.5s time-delay

$$e^{sT} = \frac{36\,s^2 - 36\,s + 12}{36\,s^2 + 36\,s + 12}$$

Equation 5-13 Pade approximation for 6s time-delay

Due to the random nature of the time-delays, the CLTF of system will have a dynamic nature. Therefore, at each value of the time-delays, the closed loop system characteristics will have a different response and varies from one time response to another. This can be clarified by deriving the CLTF of the system with the time-delays for each value listed above. From the basic control theories, the CLTF of any

two systems connected in series, as it is the case in this study where the time-delays block is in series with the system, is:

$$\text{CLTF} = \frac{e^{sT} * G(s)}{1 + e^{sT} * G(s)}$$

Equation 5-14 CLTF of two systems connected in series

Based on the values given in Page 5-105, the closed loop transfer function CLTF of the motor is:

$$G(s) = \frac{0.765}{s^2 + 112.2\,s + 6.6}$$

Equation 5-15 CLTF of the selected dc-motor

However, the effect of the time-delays does not appear clearly on this CLTF as the motor become stable quickly. Therefore, to analyse the time-delays effect for the I-bRO purpose, the motor parameters have been changed to get the following transfer function:

$$G(s) = \frac{1}{s^2 + s + 20}$$

Equation 5-16 Simulated and analysed TF for the I-bRO

A Matlab program has been developed to derive the CLTF of the system at any random value of the time-delays. This program can be revised in the appendix of this report. Therefore the system CLTF for the time-delays of the above mentioned values will be as follows:

$$G(s) = \frac{s^2 - 6\,s + 12}{s^4 + 7\,s^3 + 39\,s^2 + 126\,s + 252}$$

Equation 5-17 CLTF for time-delays of 1s

$$G(s) = \frac{2.25\,s^2 - 6s + 12}{2.25\,s^4 + 11.25\,s^3 + 68.25\,s^2 + 183\,s + 252}$$

Equation 5-18 CLTF for time-delays of 1.5s

$$G(s) = \frac{6.25s^2 - 15s + 12}{6.25s^4 + 21.25s^3 + 158.3s^2 + 297s + 252}$$

Equation 5-19 CLTF for time-delays of 2.5s

$$G(s) = \frac{16 \ s^2 - 24 \ s + 12}{16 \ s^4 + 40 \ s^3 + 372 \ s^2 + 468 \ s + 252}$$

Equation 5-20 CLTF for time-delays of 4s

$$G(s) = \frac{30.25 \ s^2 - 33 \ s + 12}{30.25 \ s^4 + 63.25 \ s^3 + 680.3 \ s^2 + 639 \ s + 252}$$

Equation 5-21 CLTF for time-delays of 5.5s

$$G(s) = \frac{36 \ s^2 - 36 \ s + 12}{36 \ s^4 + 72 \ s^3 + 804 \ s^2 + 696 \ s + 252}$$

Equation 5-22 CLTF for time-delays of 6s

The CLTF shown in the above equations indicate clearly that the system behaviors change along with the time-delays which means the system adopts the dynamic nature of the time-delays.

We will study and analyse the system response and the system behaviors for the five different values of the time-delays. These to be; 1s, 1.5s, 2s, 4s, 5.5s and 6s. A Matlab program, which can be revised at the appendix of this report, has been developed to calculate the transfer function for any value of the time-delays, plot the response of the system with and without the time-delays and determines the system poles and zeroes for each value of the time-delays. The response of the system to a unit step input and random time-delays is as shown in the following figures:
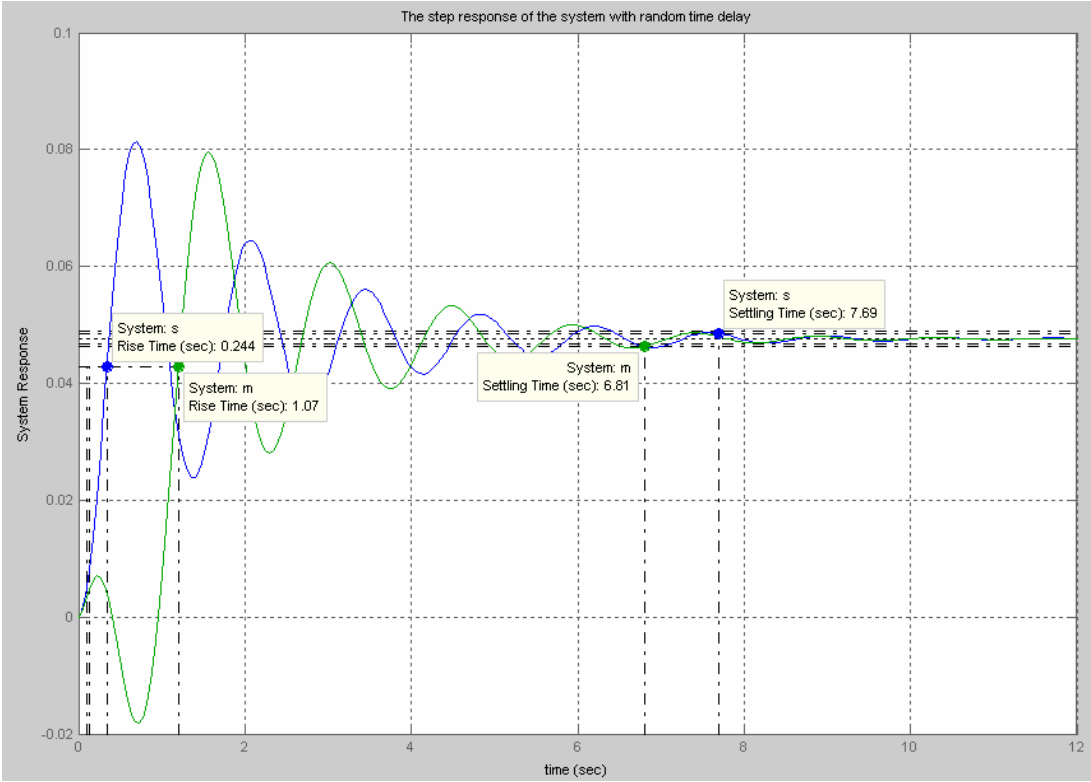
Figure 5-10 the system response to 1s time-delays
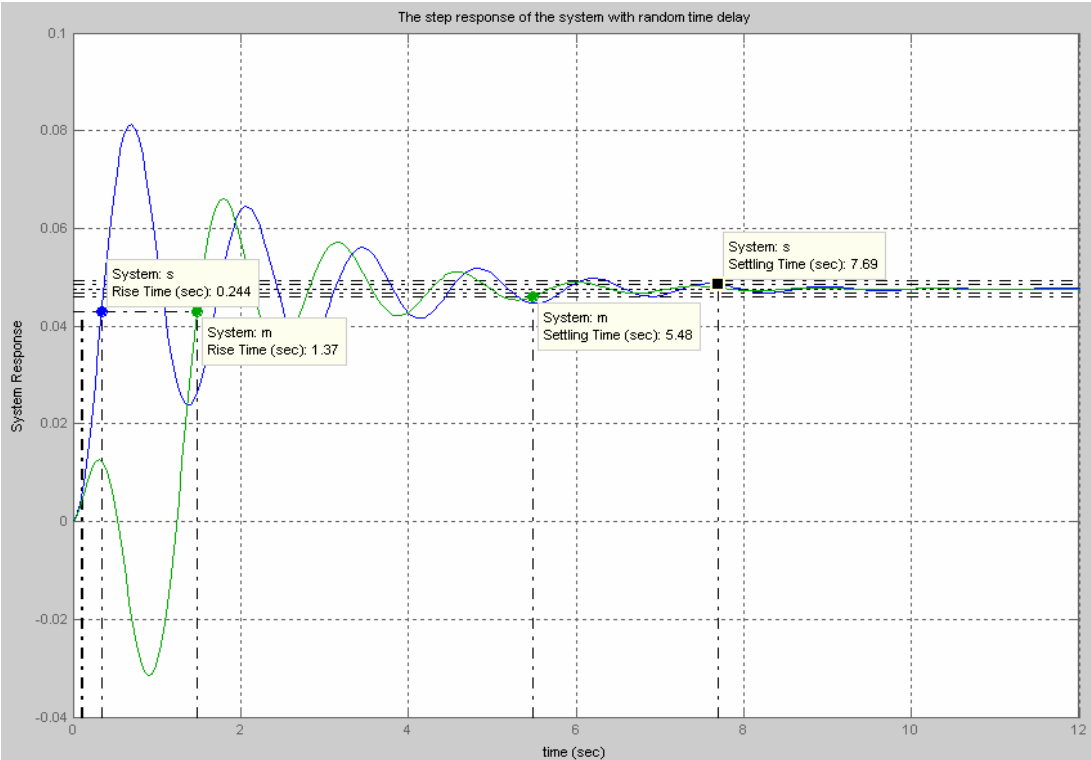
Figure 5-11 the system response to 1.5s time-delays

5-111
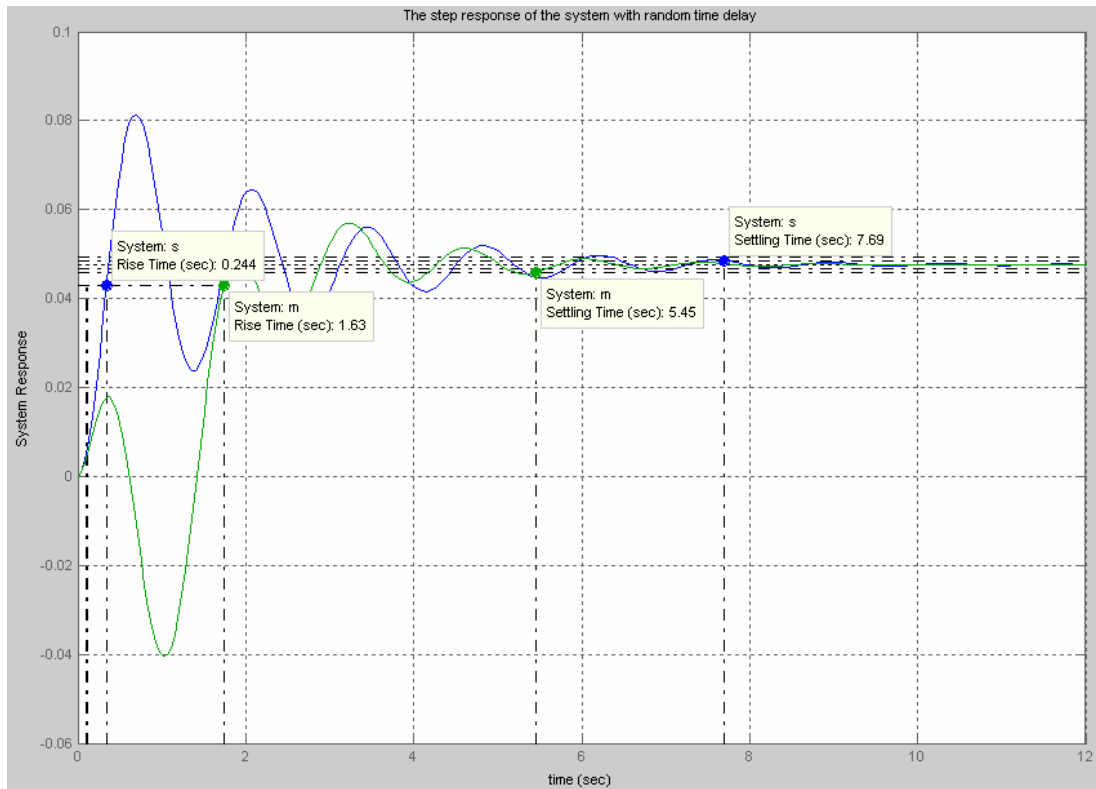
Figure 5-12 the system response to 2s time-delays
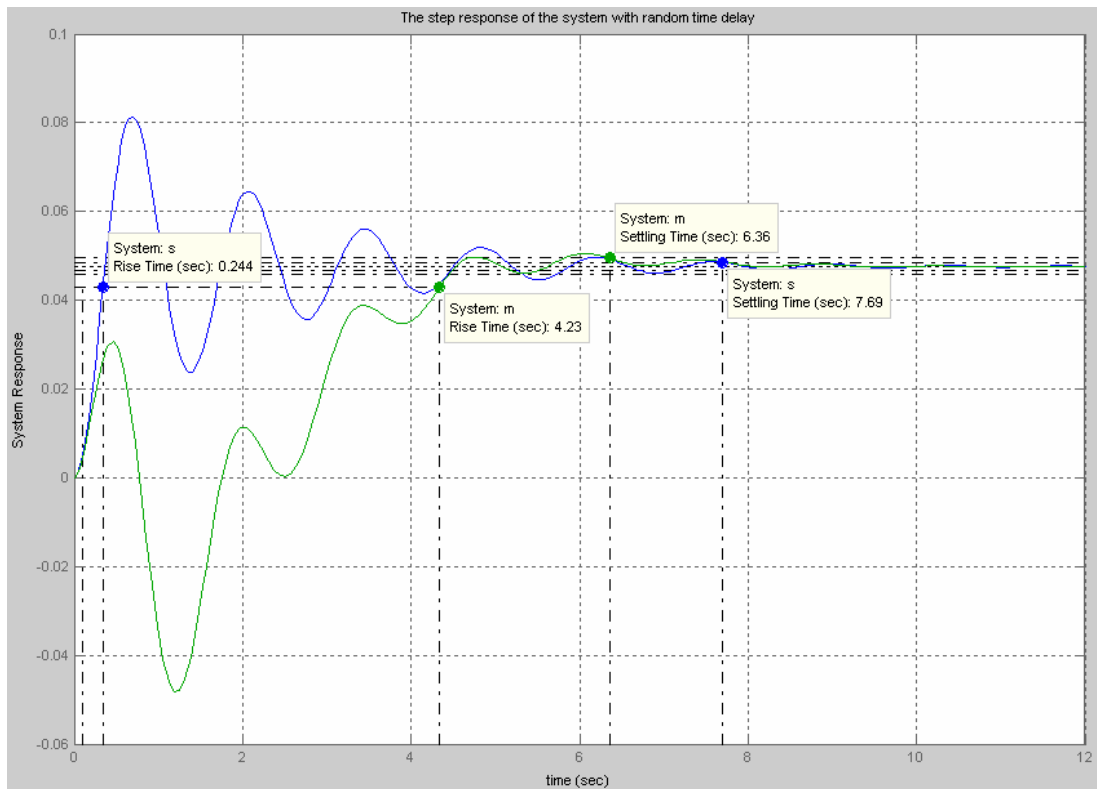
Figure 5-13 the system response to 4s time-delays

5-112
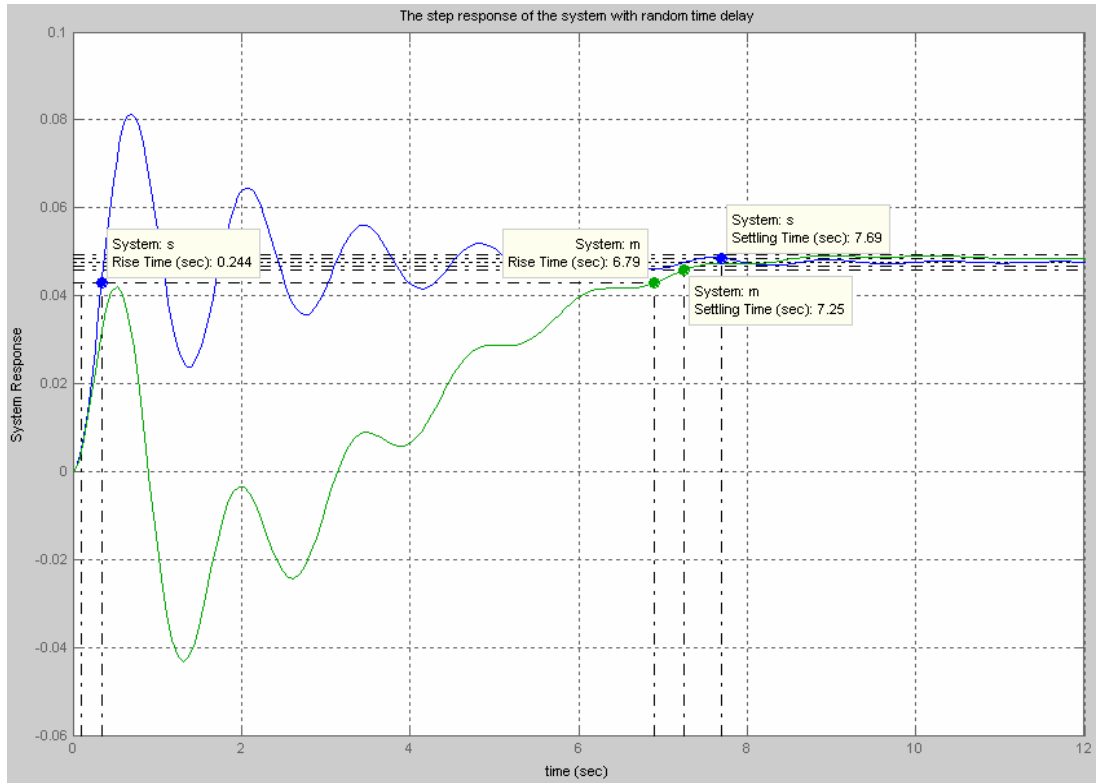
Figure 5-14 the system response to 5.5s time-delays
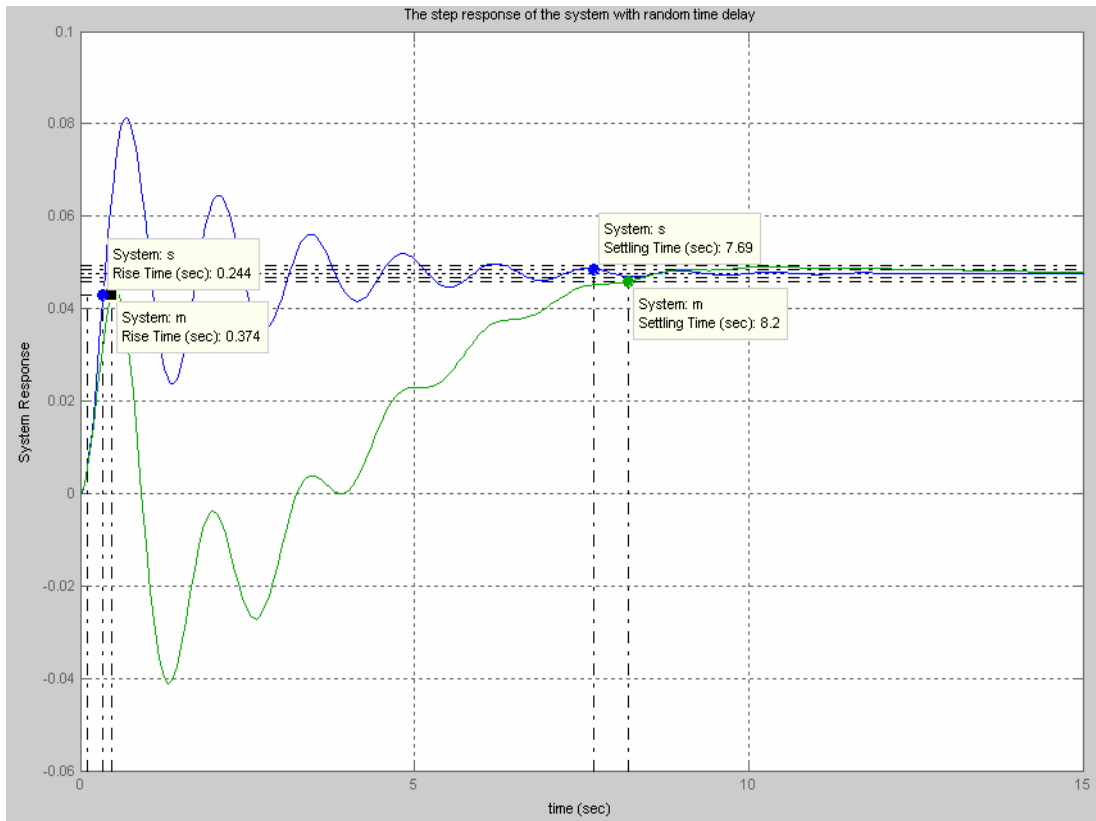
Figure 5-15 the system response to 6s time-delays

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5.6.1 Analysing the System Response to Random Time-Delays

Figures 5(10-15) are for the step response of the system with and without the time-delays affection. The blue line represents the system without the delay and the green line is for the system with the delay. At a glance to these figures, the response of the system to the step input can be analysed as follows:

1. The rising time of the original system increases alongside with time-delays. On the other hand, the settling time with the time-delayed system is less than without the time-delayed. In another words, the rising time has a proportional relation with the time-delays and inverse relation with the settling time. However, this relation does not continue for long as it can be seen in Figure 5-11, the settling time with the time-delayed system became longer than the system without time-delays.

2. The second notice from the above figures is that, the time-delays have added an inverse response to the system. The inverse response means the dynamic behavior of the system with a positive zero showing step response in the opposite direction initially to that of the steady state direction [152]. i.e. the system starts out in the wrong direction. This phenomenon degrades the entire control system performance [153]. The inverse response is produced by the zeros in the RHS of the S-plane which is clear from the root locus plot [153]. After plotting the root locus and the step response of this system, I came to notice as the zeros, which is in the RHS of the S-plane, become closer to the imaginary axis; the inverse response becomes deeper and clear in the system response. That happens alongside with the increment in the time-delays values. At the time-delay was 1s, the zeroes were three intervals far from the imaginary axis while at the time-delays was 6s, the system zeroes were at half intervals far from the imaginary axis.

3. The third notice, the initial system has a damping nature till it settles at the steady state value. The system with time-delays starts as a damping system and as the time-delay increases the system turns to be over-damp system. All damping phenomenas occur in the over-damp region or under the steady-state value. In other words, the original system damping ratio was less than 0.5 and the time-delay has increased this ratio by more than double and thus the system was shifted from the over-damp condition to the under-damp

condition.

4. The time-delay has no affection on the system at the starting as the system responded immediately to the input without any delays.

5. From these figures, it is very clear that, the time-delays have no affection on the system stability. The original system is stable and it remains stable even with different and random time-delays. The time-delay has delayed the system stability. That is supported by the root locus plot of the system. In that plot, which is in the appendix of this report, all system poles are in the LHS of the S-plane (negative values) which means the system is stable for the given time-delays. The poles and zeroes of this system for the given time-delays have the values shown in Table 5-2.

Time-delay (s)	Poles	Zeroes
1	-0.5783 + 4.3120i , -0.5783 - 4.3120i -2.9217 + 2.1858i ,-2.9217 - 2.1858i	3.0000 + 1.7321i 3.0000 - 1.7321i
1.5	-0.6420 + 4.4198i ,-0.6420 - 4.4198i -1.8580 + 1.4706i ,-1.8580 - 1.4706i	2.0000 + 1.1547i 2.0000 - 1.1547i
2	-0.6292 + 4.4807i , -0.6292 - 4.4807i -1.3708 + 1.0946i , -1.3708 - 1.0946i	1.5000 + 0.8660i 1.5000 - 0.8660i
4	-0.5723 + 4.5408i , -0.5723 - 4.5408i -0.6777 + 0.5410i , -0.6777 - 0.5410i	0.7500 + 0.4330i 0.7500 - 0.4330i
5.5	-0.5530 + 4.5493i , -0.5530 - 4.5493i -0.4925 + 0.3926i ,-0.4925 - 0.3926i	0.5455 + 0.3149i 0.5455 - 0.3149i
6	-0.5486 + 4.5507i , -0.5486 - 4.5507i -0.4514 + 0.3597i , -0.4514 - 0.3597i	0.5000 + 0.2887i 0.5000 - 0.2887i

Table 5-2 poles and zeroes of the system

6. System time constant has been increased as an affection of the time-delays in all cases in the above figures. It means the system will take longer time to reach the steady state value.

5.7 State 2 Open Loop System

This state represents the system when the internet or the network server is cut off and no communication between the input and the output of the control system thus the control loop will be opened. Basically, as it has been stated before, the system does not change between the two states in a constant style or in a known fashion to the user. Instead, it jumps between the two states randomly. The system with such behaviors is called jumping linear system [154]. The jump linear systems are defined as a group of linear systems with randomly jumping parameters and are used to model systems subject to failure or change in structure [155]. The literature is rich with the mathematical modeling of such systems [154], [155], [156]. In the literature, this system is also known as linear Markovian jump systems.

In this section, the system behaviors during the jumping state will be analysed. A Matlab program, which can be revised at the appendix of this report, has been developed to analyse the system in the jumping or transition state. The flow chart in the appendix is clarifying how the Matlab program runs to simulate the system. As the system jumps from one state to another randomly, the transient response of the system to a unit step input depends on the initial conditions of the system. The initial conditions of each state are the final conditions of the state just before. In another words, the final conditions of x-state will be the initial conditions of x_{+1}-state and so on. For x_0-state, the initial conditions are assumed to be zeros. The simulation results of the system response during the jumping states of different cases are shown in the following figures:
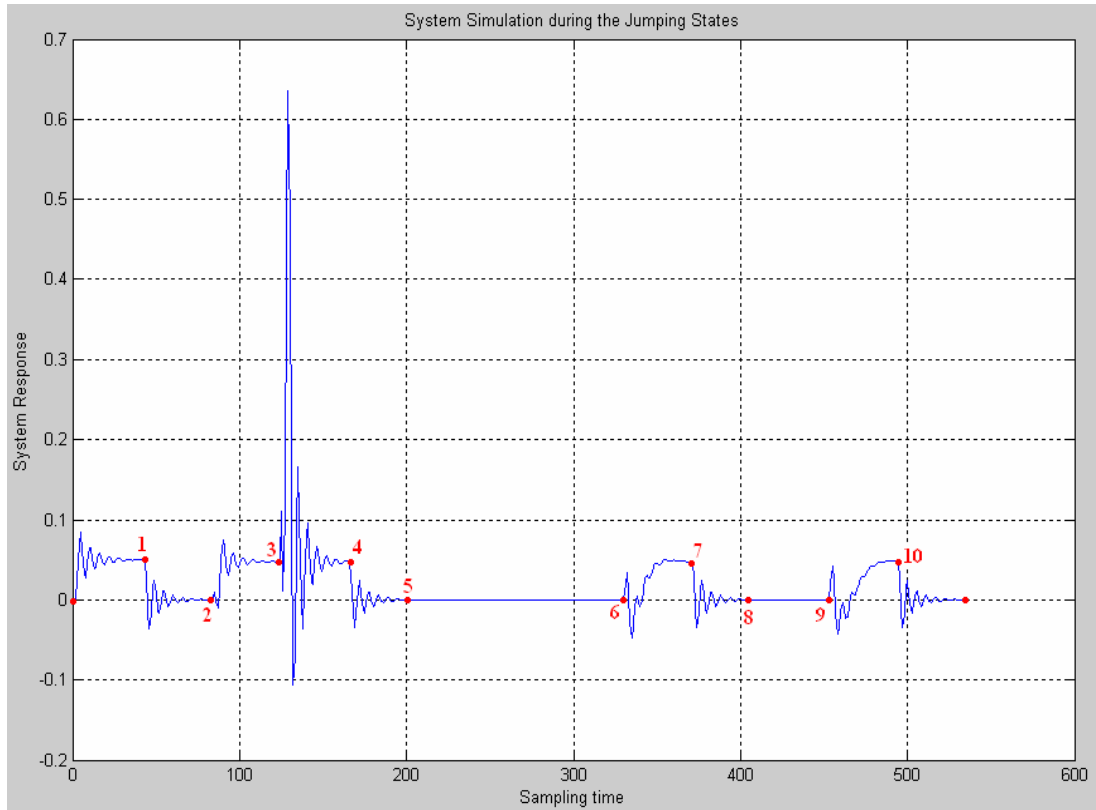
Figure 5-16 case 1 of the system during the jumping state
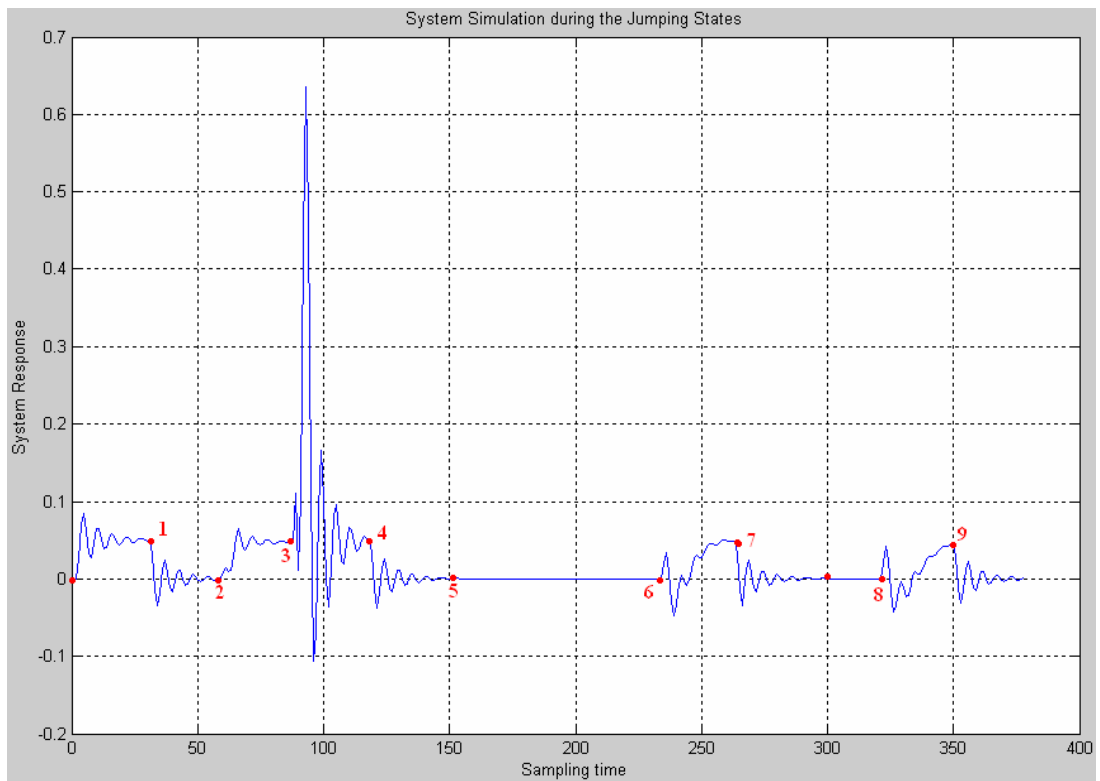
Figure 5-17 case 2of the system during the jumping state

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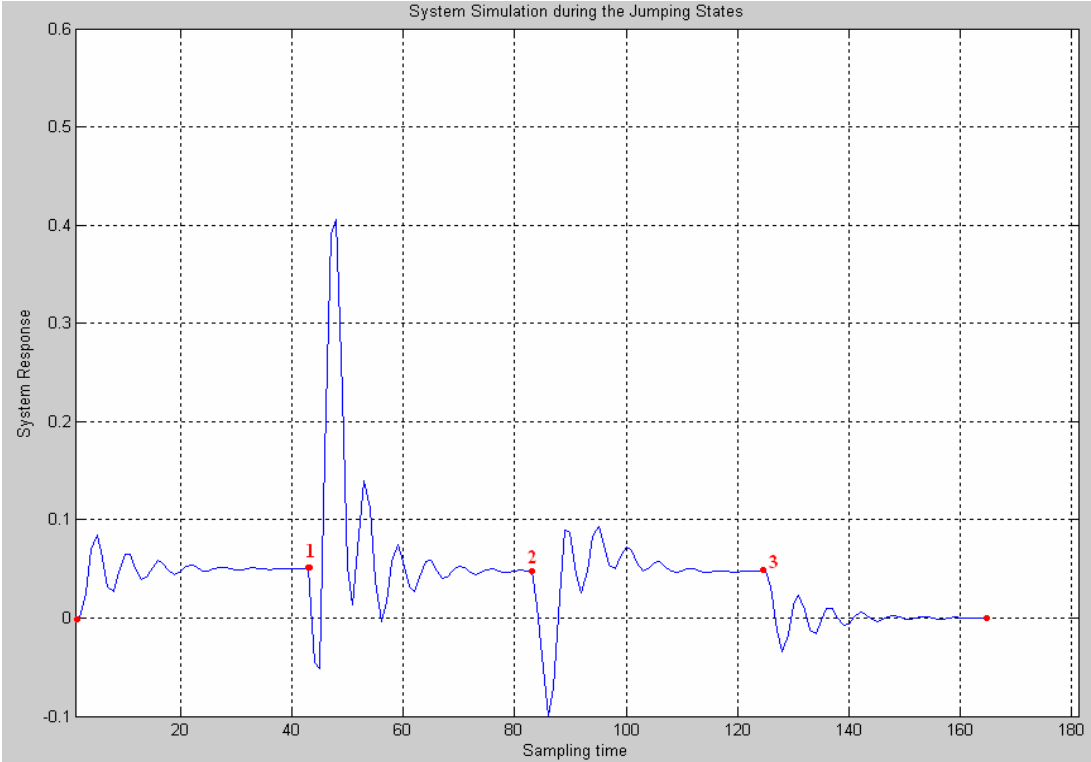
Figure 5-18 case 3 of the system during the jumping state
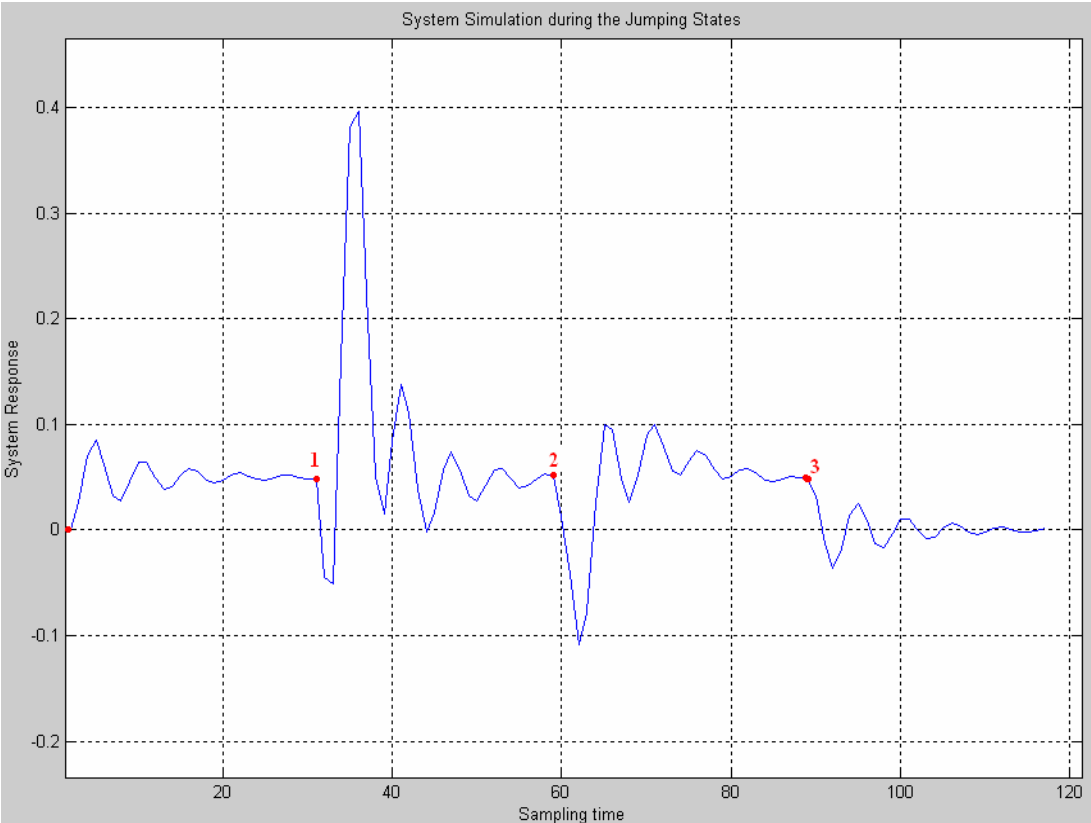
Figure 5-19 case 4 of the system during the jumping state

5-118

5.7.1 Analysis the System Response of the State 2

Figures 5 (16-19) are for the system during the jumping or the transition state. The above figures illustrate clearly the system behaviors when it jumps randomly between the two states. We will start analysing Figure 5-16 as follows:

1. From point zero to the point one, the system was running with a unit impulse input and zero initial conditions. The system reached the steady state value and at the end of this portion (0-1) it became stable.

2. Suddenly, the network server disconnected and the system characteristics changed. As it can be seen in portion two (1-2), the system felt gradually from the steady state value to the zero value. In this portion, the system has no input as the loop is opened. However, the initial conditions were the last values of the previous state. These conditions kept the system running for small portion of time and prevent it from the sudden stop which is impractical.

3. In portion (2-3) and after the system dead (completely stopped) in this portion (1-2), the network communication was resumed and the loop was closed again. In this point, the system was running under the closed loop condition with some time-delays. As the system started from the zero point (dead state), the initial conditions for this portion (2-3) were zero while the input was the unit step. The system was running under these conditions for some time and suddenly the time-delays changed for the next portion (3-4). The change in the time-delays can be noticed in the system response as it sharply increased from the steady state to a higher value. This portion (3-4) was running under nonzero initial conditions and under the unit step input. By the end of this portion the system settled down in the steady state value.

4. Suddenly and in an expected fashion, the server disconnected again therefore the system run under the open loop condition. This is in portion five (4-5) in which the input was zero while the initial conditions were not zero. The network server took longer time to resume the connection than it did in portion (1-2) and the system dead completely and settled in zero position.

5. After some times, the server resumed the communication connection and the system run under zero initial conditions and with the unit step input. It was running for short time and before it settled in the steady state condition the

server cut off again and the system returned gradually to the zero position (6-7, 7-8, 8-9). At point nine, the loop was closed again with different value of time-delays. The system reached the steady state condition but before it settled there the server cut off and thus in next portion the system returned to the zero position.

The simulation and analysis of the Figure 5-16 is exactly the same case in Figure 5-17 with the difference in the control cycle duration. Therefore the same analysis that have been made for Figure 5-16 is applied for Figure 5-17. However, the only difference between the two cases of Figures 5(16-17), the system in Figure 5-16 became stable in some portions while it did not in the case of Figure 5-17.

If we look to the case simulated in Figure 5-18 it is quite different than the two cases in Figures 5(16-17). The case in Figure 5-18 can be simulated as follows:

1. The system started with zero initial conditions and with the unit step as an input. The system settled in the steady state value for some times and suddenly the network experienced some time-delays in the communication.

2. The system response changed as a result of the time-delays from point one (1-2). The system in this portion (1-2) was running under nonzero initial conditions and with the unit step as an input. The system tried to settle at the steady state value but again the network experienced time-delays with a different value and the system response changed accordingly (2-3).

3. In this portion (2-3) the system was running with nonzero initial conditions and the unit step as an input. Again the system settled at the steady state value for short times.

4. Suddenly, the network server disconnected and the communication between the system and the controller disappeared (3). The system in this portion was running under nonzero initial conditions but with zero input. The initial conditions maintained the system running for some times till it dead rather than dead suddenly which is impractical.

The case simulated and analysed in Figure 5-18 is exactly the same case in Figure 5-19 with the difference in the control cycle duration. The same analysis made for Figure 5-18 is applied for Figure 5-19.

However, the above cases that have been simulated and analysed for the I-bCS represent the worst cases in which the time-delays occur frequently each 7-10s. If that is the situation with the internet server, it would be difficult and impractical to

integrate the control system with the internet as the controlled system will never settle and remain in the steady state condition for long time. In another words, by the time the control system becomes stable, it will be interrupted by the sudden time-delays or the server disconnection and will run under new operating conditions. With these scenarios, the user will not be able to anticipate the output of the controlled system and the system become out of control. The practical scenario, which is more likely to happen in the internet environment for the applications of the I-bRO, is in which the controlled system will reach the steady state value and will continue running there for an undetermined time but definitely longer than the duration with the previous scenarios. In this case, the user can remotely operate the system and control it over the internet and the system reaches the steady state. This scenario, for the same system that was simulated in the above figures, is shown in Figure 5-20 and Figure 5-21. If we try to analyse these figures we can notice that the system, although it jumps between the two states and it is subjected to the random time-delays and the sudden change on the operating conditions, but it stays stable for long time in each state during which the remote operation can take place. It is in contrast to the previous cases.
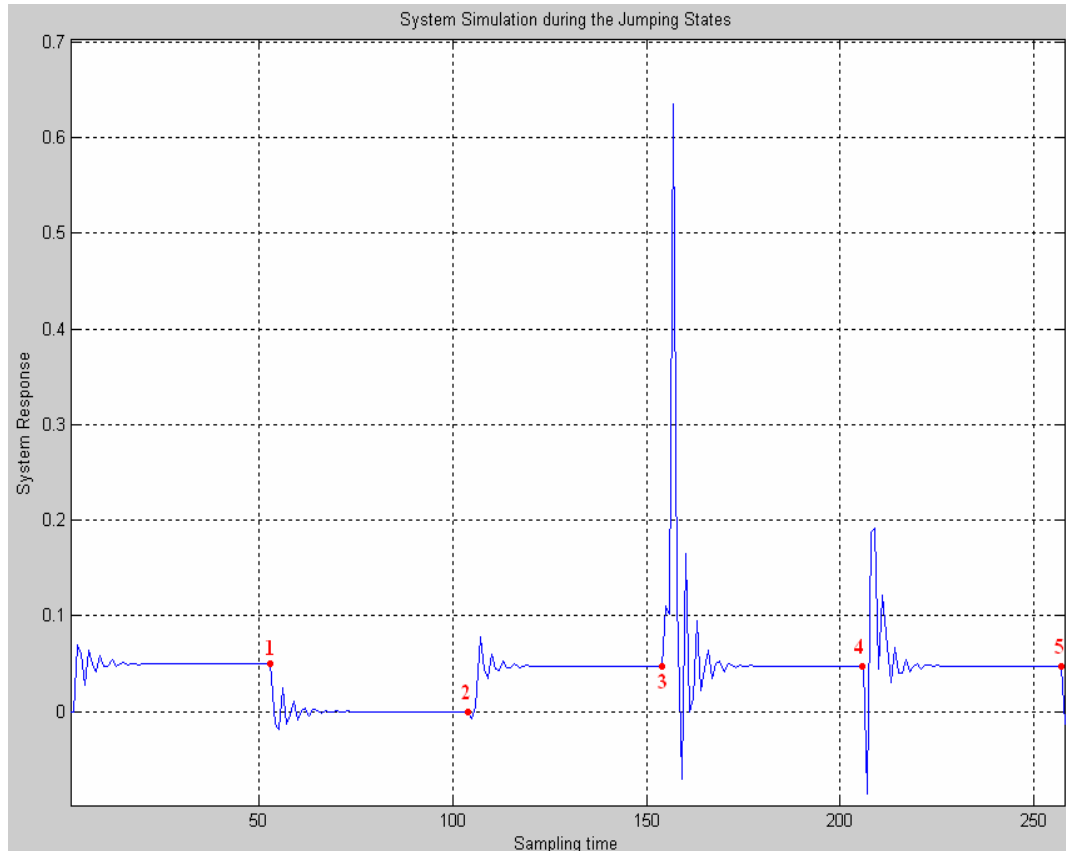
Figure 5-20 the system in Figure 5-17 but with longer steady state time
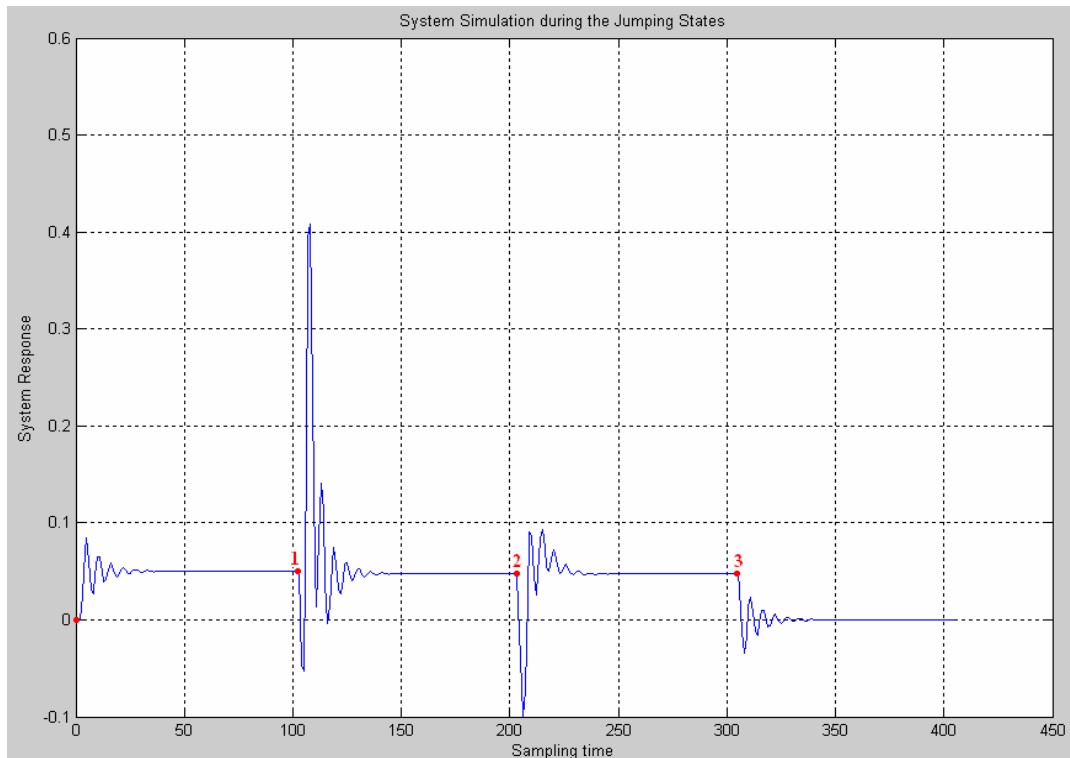
Figure 5-21 the system in Figure 5-19 but with longer steady state time

In general, the length of the time-delays or when to happen or when the internet server will cut off, all these issues are out of the internet user knowledge and anticipation. Due to that, the I-bRO developers and designers have to take these issues seriously into consideration during the designing stages and something that are part of the system design as yet there is no escape from them. The future internet server could avoid this and improve the quality of the service which we all looking for it. Nonetheless, as it has been mentioned in an earlier stage of this report, there are different methods that have been developed and used for providing the internet service. Each method has different time-delays characteristics and has a different influence in the internet time-delays. As such, the analyses and simulation that has been carried out in this report for the I-bRO is for the TCP/IP communication protocol and for the service provided by the dial-up method only and does not cover the other methods and techniques.

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5.8 New Design for the I-bRO

To enhance the control system performance of the I-bRO in the existence of the time-delays, a new control system design with two controllers; local and remote has been proposed in this study. It is similar to the design implemented in another study [49]. Figure 5-22 illustrates the proposed design with the two controllers. The local controller is located between the network server and the system under control. It is incorporated with some degree of intelligence in order to handle the time-delays effects on the entire system performance. The system database is stored in this controller memory and thus it will be able to modify the system set points or the operation conditions and adopt the process to the new operating conditions during the random time-delays. The human interfere is expected to happens only during abnormal operating conditions or to update the local controller with new databases. The intelligent local controller has two modes of operation:

1. Mode1. In this mode it monitors the operation of the entire control system. It has no task as long as the time-delays between the remote controller and the system have not exceeded a value predetermined by the system operator.

2. Mode2. When the time-delays between the remote controller and the system exceed the predetermined value or the network server is interrupted, the intelligent local controller replaces immediately the remote controller. It will continue in this mode and run the system until the time-delays is reduced or the connection between the plant and the remote controller is resumed and then it goes back to mode one in which the remote controller run the system.

The intelligent controller will be supported with a soft switching mechanism that facilitates the changeover between the two modes. This design is similar to the VSPC design which has been already implemented as they are two controllers running the process and one of them is incorporated with degree of intelligence [49]. However, this design is different from the VSPC design as the VSPC is invoked only to update the local controller parameters or the system set points otherwise the local controller controls the process. With the new design, the remote controller controls the process until the time-delays between the controller and the system exceeds an acceptable value to the system then the local intelligent controller interferes and continues

controlling the process until the time-delays is improved.
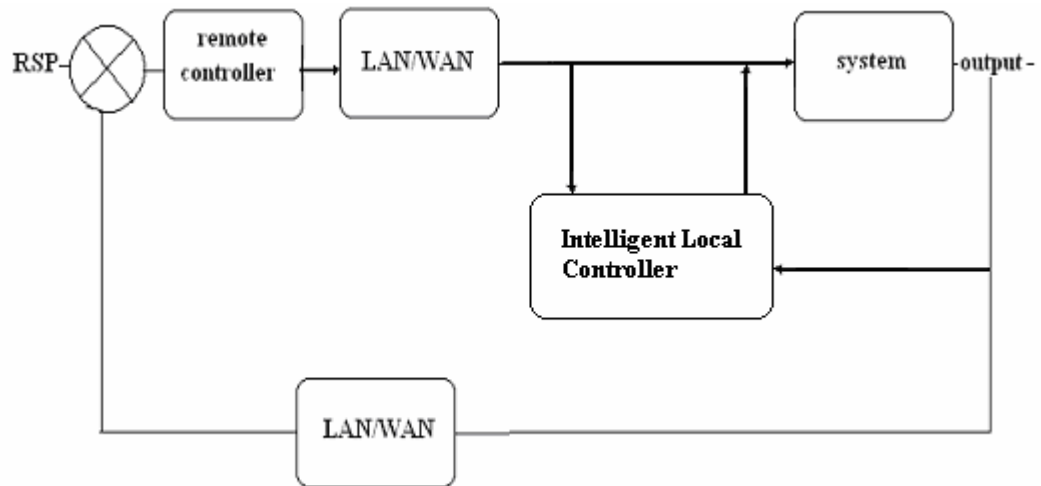
Figure 5-22 block diagram of the modified I-bCS

As it can be seen in Figure 5-22, the new design eliminates the network path when the time-delays exceed the predetermine value. The system acts as a fully automated control system run by the database stored in the local controller memory and gathered from the system history.

5.9   I-bRO Application Requirements

The need to control processes with time-delays can be found in many aspects of the industrial life starting from refining to rolling mills [157]. In order to apply the I-bRO for the real-time applications, several factors and issues, associated with the internet, have to be addressed. Some of these are [90]:

1. The selection of the communication protocol
2. Authorised users restriction
3. Multiple-users operation system
4. Security

5.9.1 The Selection of the Communication Protocol

IP, UDP, and TCP are the three basic tools for the network communication [158]. Real Time Protocol (RTP) Each tool is applied for different applications. The TCP/IP is available on most computers and thus it has the potential to transfer information among diverse systems [158]. The TCP/IP protocol can be used to establish a communication between the server and the client over single networks or interconnected networks [158]. The TCP ensures reliable transmission across networks, delivering data in sequence without errors, loss, or duplication [105]. The TCP/IP is a confirmation based protocol as it retransmits the datagram until it receives an acknowledgment from the receiver [106]. The great advantage of the TCP/IP protocol is the reliability in which there is no data losses during the communication between the client and the server [106]. Nonetheless, the reliability feature is one of the reasons behind the slow of the overall transmission rate in this protocol [159]. TCP is ideal for the I-bRO implementation where the system requires frequent parameters adjustments [108]. However, with the TCP/IP protocol, the client needs to specify the IP-address and port number of the server; several clients with the same IP-address but different ports can be concurrently connected to the same port of the server [158]. Furthermore, the TCP/IP protocol based communication, is unfavorable for the real-time applications as the data sampled at different points in time will arrive simultaneously [106].

On the other hand, the UDP protocol provides communication that is not guaranteed between two applications on the network [106]. It can be used in applications in which reliability or data losses are not crucial [158]. However, for the

real-time applications, where the data transmission speed is a crucial factor, UDP is preferable and it is expected to perform much better than the TCP [90].

The internet protocol for the real-time applications is the Real-time Transport Protocol (RTP) [159]. It is often preferable over the TCP and the UDP for the real-time applications[159]. However, the RTP does not guarantee data delivery between the two side of the network communication as it is the case with the UDP [159].

The communication protocol that has been used in this study for the remote operation between the client and the server is the TCP/IP as it is available on most computers and it can transfer information among diverse systems. Furthermore, the test-rig under study is not a time critical system in which delay in the data transmission will not affect on the system. Beside that TCP/IP is easy to be developed by the LabVIEW program.

5.9.2 Authorised Users Restriction

This issue is one of the important issues that need to be addressed in the I-bRO. As it has been mentioned above, the system connected to the internet network is opened to the public and likely to be accessed by unauthorised clients. Hackers are continuously developing new methods to penetrate different systems. Literature survey has not mentioned different methods been applied to handle this problem. User identification scheme and domain-based access restriction has been suggested and implemented [90]. Utilising the security service or at least a first level of security provided by the web service to allow selected groups of authorised users to get suitable client applications by login and password schemes has been shown [77].

In the development software of this study, two methods can be used to control the access to authorised users only. The first method is to identify different users by the machine IP addresses. The program is designed to grant access to particular IP addresses, predetermined in the program developer, and reject any other machines out of these addresses. The LabVIEW program supports this feature. The second method is to apply the same scenario but at the web site level. The web site has been designed with username and password feature, which they can be given to the right users only. This feature has been detailed previously in this report

5.9.3 Multi-Users Operation

Traditional remote control support multi users to operate simultaneously. This

feature could be applied in the I-bRO but under certain conditions. That is because in the traditional method, users normally sit in the same operation room and they easily coordinate between each other [49]. On the other hand, the internet users are geographically distributed and the traditional coordination method is not a practical solution if not impossible to be applied thus there must be a mechanism that coordinates between the different users.

There are some methods have been applied to tackle this issue. Some software developments have the facility to coordinate between different users. The software queue different clients and schedule them in a sequence, as it is the case with development program of this research (LabVIEW). In the normal operation, the first user will get the chance to control the system. When another user asks to have a control turn, the LabVIEW program will automatically send a message for the first user informing him about the second user request. Beside that, it will give the first user limited time to finish his operation or to coordinate with the second user. If that time passed, the control privilege will be automatically transferred and given to the second users. This process is repeated with each new control request. Beside that, the development program of this research restricted multiple users by the software licence and it needs an individual licence for each user. Due to that, we could not handle and investigate the multi-users operation on the research test-rig. This method which is the software facility has been discussed and applied by several researchers [49], [90].

5.9.4 Security

When designing an I-bRO, the designer has to insure the system is protected from the outside attackers. One method that has been used protect the system is by using the security features available through the software [112]. The most common method that has been applied to insure the system security is the user identification method in which the system responds to particular users with a case sensitive password recognised by the system [130]. Features such as password protection can prevent private information from being subjected to the public. This feature is useful for offering on-line experimentation when students need to gain access to inaccessible laboratories outside of their class time. The password feature or the prove of identification has been applied in this study. However, this feature in not sufficient to protect the system from hackers.

6 Conclusion and Future works

This study focused on the design issues, investigation and implementation of the internet-based control and monitoring of a dynamic system. The study covered the two sides of this issue, the software and the hardware. The software side includes the design of the VIs, which has been developed by the use of the LabVIEW7 program, to replace the physical M&T instruments. Beside that, the MATLAB program as software has been used to analyse and simulate the dynamic system performance over the internet. Furthermore, this side covers the software related to the internet applications for the remote operations. The other isde; the hardware, includes the design and the setup of the test-rig. Beside that, this side includes the design and the development of all apparatus that have been used to facilitate the test-rig operation, for it, to practice and investigate the I-bRO.

In order to investigate the I-bRO, the study has been undergone through several stages as follows:

1. Choice of the test-rig system with all its apparatus that is suitable for the applications of the I-bRO.

2. Design the Virtual Instruments (VI) that will replace the physical M&T instruments of the test-rig. This stage has been achieved by the use of the LabVIEW7 program from National Instrument.

3. Design and development of the required elements that will be used to facilitate the operation of the test-rig for the I-bRO.

4. Design and development of the Computer-based Instrumentation System (C-bIS). That has been achieved by combining and interfacing the test-rig apparatus with the local computer.

5. Investigate the local operation setup of the test-rig from the local computer located by the test-rig.

6. Design and development of the LabVIEW remote front panel. This panel has been used to implement the remote operation of the test-rig.

7. Investigate the remote operation of the test-rig over the Local Area Network (LAN).

8. Investigate the remote operation of the test-rig over the Internet (WAN). By this stage, the I-bRO has been developed, practiced and testified.

9. Study the performance of the test-rig operation over the LAN and WAN.

10. Simulation, analysis and discussion of the I-bRO.

11. Suggestion and solution to improve the performance of the test-rig in the internet environment.

As it has been mentioned at the beginning of this report, this study has been carried out in a form of an on-line and real-time Virtual Laboratory. This has been developed by combining both; the test-rig apparatus and the developed Virtual Instruments. The advantages of the VIs in the educational and the research sides have been realised. Generally, they simplify the entire M&T system beside the cost reduction of the system development. Instead of monitoring and controlling each instrument individually, the VI front panel gather all of the M&T instruments of the system in one panel, which makes it easy for the system operator to follow the system. The test-rig that has been selected for this study has a dynamic nature. The developed VL has been practiced and testified several times to operate as it has been planed. Generally, a highly reliable and flexible real-time Internet-based Monitoring and Controlling of a dynamic system has been developed. The study test-rig was firstly set up for the local operation and the system performance was recorded. In the second stage, the test-rig was modified to support the remote operation and the system performance was recorded again.

In this study, the remote operation test of the system has been mainly carried out over the LAN of the University. It has been noticed that the test-rig responses to the user commands during the remote operation in a duration of one to three seconds. It is relatively small period to the selected test-rig but in some control system such as in the industry, this period is considered to be long time-delay. The communication time-delays can be explained by the LAN server characteristics, the traffic load on the server that varies from one time to another and the amount of the data transfered. The same scenario has occurred in the remote operation over the internet. As it has been stated previously in this report, I-Primus Telecom server has been used for I-bRO. With the internet connection, the communication time between the remote user and the system was expected to take longer time than the case with the LAN. That expectation is based on the affection of some factors associated with the I-bRO such as the distance between the two communication parties, the internet load, the quality of the service of the internet provider and the quality of computers and their peripherals. However, the result of the time-delays with the internet was almost

similar to the time-delays, which have been experienced with the LAN, with some variations in sometimes. My explanation to that is one of the followings:

1. The characteristics of the I-Primus Telecom server such as the transmission speed, the bandwidth or the bit transmission rate, are more advanced if they are compared to the server of the University. The advance characteristics improve the quality of the service and consequently reduce the time-delays.

2. Although I-Primus Telecom is a public internet service provider, the traffic load (number of users) in this server during the daytime maybe less if it is compared with the university network in which it is very busy during the daytime.

The above explanations are not based on any scientific figures of users or the network characteristics.

Unfortunately, through the literature I have gone through, the developers and researchers have not discuss intensively different issues and factors that affect on the I-bRO as much as they discuss the methods of developing the system itself. Quite few of them has discussed and addressed the issue related to the internet time-delays or the data losses. Some of the researchers suggested not utilising the internet for the remote operation of critical systems. Therefore, before one can decide and approve the possibility of applying the I-bRO on a process plant, all problems associated with the internet have to be addressed first.

In this study, the I-bRO over the internet for the dynamic system has been modeled and simulated by the use of the Matlab program. The simulation covered two cases; the closed loop and open loop control system. The internet server is modelled by a switch that flips randomly between on and off positions. In the first case, the switch is assumed to be closed. The results of the simulation of the closed loop control system with the time-delays associated with the internet have shown that, the time-delays, although degrade the control system performance but doe not affect on the system stability. It does so by increasing the settling time, rising time and the system time constant. However, the unexpected results that has been noticed was to find that, the time-delays applied for the system under this study (up to 20s) have no affection on the system stability irrespective to the time-delays values where the system remains stable for all these values. This result different from the result shown in some literature [106], [130] ,[142], [143] that indicated the time-delays make the system loose its stability. Furthermore, for the above simulated time-delays, the

system poles are in the LHS of the S-plane which is a clear sign of the system stability. In the second case of the system operation, open loop system, the internet server is subjected to a random disconnection with random time-delays. However, the system in this case is not an open loop system continuously as the switch closes and opens randomly. Under this case, it has been found the system is running with two factors; the input and the initial conditions to the system depending on the switch position. When the server is disconnected, the switch is opened; the system is running with the initial conditions only.

As a general conclusion in this aspect, the feasibility of the remote operation over the intranet or the internet have been experimentally investigated and proven. However, the real-time operation is not possible yet as the internet server is subjected to different issues that have not been solved such as the data losses, security and the time delays. The experimental results that have been found in this research show that time-delays experienced on a public internet server or in the university server could reach up to three seconds. As it has been mentioned, half second is considered to be a significant time-delay for some control systems. As such, the I-bRO is not recommended to be applied for the industrial process plants where a very small time-delay affects negatively on the process. At this stage of the internet technology, the Internet-based Monitoring of a process plants can be easily practiced.

The work that has been conducted in this research can be modified and developed. Because of the time constraint for this study, I left some modifications and developments for the future. Some of the developments and modifications that I have planed to add are:

1. Incorporate the test-rig with web or a video camera to capture real-time and live image of the test-rig during the operation. By this step the client (remote user) is expected to have a broader vision of the system instead of receiving a textual data although it is in a VI style.

2. The VI that has been developed by LabVIEW program can be modified and developed in different ways. The developer can debug this program in a way it will be able to detect the test-rig connection and wiring. By this, the remote user will be able to connect the test-rig apparatus remotely and the program will check the connections instead of the human interfere. This has been left for the future progress.

3. Increase the number of clients to handle multiple-clients operation and that

is by providing the necessary license.

4. Allow the client to save the data in a file and use it as a reference or for the off-line analysis. This feature is restricted to the remote user sharing the same network with the local computer (server).

5. Extend the developed system to another remote operation for teaching, research, medical or industrial applications.

6. Design and develop an automatic controller that can monitor and run the system in the internet environment.

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8 Appendixes

8.1 Test-rig Connection Details

1. Energise the external power supply that drives both the IM with the DC-Dynamometer.

2. Connect the high-voltage switches , the SIS & LIS, as follows:

   - SIS is connected between the local computer, via the load control box, and the phase line on the IM front panel.

   - LIS is connected between the local computer, via the load control box, and the main connection on the dynamometer front panel.

3. Ensure the 220VAC supply that runs the high-voltage switches (LIS & SIS) is ONN.

4. Connect the load control box to 5VDC supply, to drive the buffer.

5. Connect the M&T instruments with the test-rig properly. The NANOVIP Plus is connected to the IM side while the load cell is connected from the DC-Dynamometer shaft side. The connection details is shown and explained in the main report.

6. Connect the M&T instruments, the load control box and the IM tachometer to the local computer by the mean of the interface.

7. Connect the local computer to the power supply and energise it.

8. Open the LabVIEW program and go to this file: Last Version Program2.

9. Once you are there, go to the instructions given in section 4.3.1 of this report. For the remote operation of both LAN and WAN, go to the remote operation sections in this report.

8.2 *Comparison between the Internet Service Providing Techniques [138]*

8.2.1 DSL vs. Dial-Up

Issues	DSL	Dial-Up
Speed	**DSL** offers guaranteed speeds (symmetrical up to 1Mbps or 35 times faster than 28.8Kbps analogue modem).	**Dial-Up** access offers speeds up to a maximum of only 56 Kbps.
Flexibility	**DSL** provides Internet access to multiple PCs/end users on one single connection, thereby not charging extra for all additional PC/end-user access. **DSL** is a fully scalable service possessing a wide range of potential speeds that are inexpensive and easy to upgrade.	**Dial-Up** access is capable of providing Internet access to only one PC/end-user, thereby charging extra for each additional PC/end-user access. **Dial-Up** access is not a scalable service due to its bandwidth limitations of 56 Kbps.
Reliability	**DSL**, by being dedicated, avoids disruptive and time-consuming process of dialling in for Internet access.	**Dial-Up** access is faced with the sometimes-tedious process of dialling in for Internet access.
Price	**DSL** is priced on a flat monthly rate with no additional usage/toll charges. **DSL** can be cost-effectively divided among multiple end-users for simultaneous	**Dial-Up** access can have costly per-monthly usage/toll charges in addition to Internet access. **Dial-Up** access must be provided with individual lines and modems for multiple end users to have simultaneous access.

Issues	DSL	Cable Modem
		access on a single connection.

8.2.2 DSL vs. Cable Modem

Issues	DSL	Cable Modem
Speed	**DSL** offers a wide range of guaranteed speeds as high as 1Mbps (symmetrical).	**Cable Modem** exists on a shared network thereby making speed performance unpredictable; it is entirely contingent on network traffic volume.
Security	**DSL** is on a closed, dedicated circuit making it less susceptible to outside hackers.	**Cable Modem** is on a shared network making it more vulnerable to hackers.
Reliability	**DSL** is on a closed, dedicated circuit enabling Crocker Communications to offer guaranteed speeds.	**Cable Modem** exists on a shared network thereby making speed performance unpredictable. **Cable Modem** may have multiple sources (or companies) providing local service and Internet access to consumers, which takes away the convenience and accountability that, comes with a single-source service provider.
Accessibility	**DSL** utilizes ubiquitous, 100-yearold telephone	**Cable Modem** utilizes young network infrastructure that is

	infrastructure (RJ-11 jacks, copper phone wire, data backbones, etc.), which makes up nearly 100% market accessibility.	shown to have sporadic and inconsistent service availability. **Cable Modem** has a slower rate of market infiltration because growth of accessibility is often on a case-by-case basis.

8.2.3 DSL vs. ISDN

Issue	DSL	ISDN
Speed	**DSL** offers a wide range of guaranteed speeds up to 1Mbps (symmetrical).	**ISDN** offers guaranteed speeds only up to 128 Kbps (which run on two channels at 64 Kbps each).
Flexibility	**DSL** is a fully scalable service possessing a wide range of potential speeds that are inexpensive and easy to upgrade. **DSL** offers access speed (SDSL, ADSL) variations to best suit specific operational and economic business needs. **DSL** can potentially replace or augment other existing services (dial-up, ISDN).	**ISDN** is not a scalable service; its maximum bandwidth is 128 Kbps making it unable to accomodate growing bandwidth demand.
Reliability	**DSL** has a low risk of ownership due to minimal hardware requirements.	**ISDN** has a high risk of ownership due to extensive hardware requirement.
Price	**DSL** has a low start-up cost by standard phone line(s) utilization and minimal	**ISDN** can have costly per-monthly usage/toll charges in addition to Internet access.

Issues	DSL	T1 Line
	equipment requirements. **DSL** is typically priced on a flat monthly rate for Internet access with no additional usage/toll charges.	

8.2.4 DSL vs. T1 Line

Issues	DSL	T1 Line
Speed	**DSL** is on a dedicated, closed circuit and therefore provides guaranteed speeds (symmetrical up to 1 Mbps and asymmetrical up to 7 Mbps).	**T 1** is on a dedicated, closed circuit and therefore provides guaranteed speeds up to 1.54M (max).
Security	**DSL** is on a secured dedicated circuit, which makes it less susceptible to hackers.	**T 1** is on a secured, dedicated circuit, which makes it less susceptible to hackers.
Flexibility	**DSL** often offers bundled, value-added services (voice/data, managed network services, long distance and local services, web hosting, and e-mail) from one provider on one invoice. **DSL** is a fully scalable service with quick and easy speed upgrade (no truck roll out).	**T 1** is a fully scalable service; however, a site visit is required for speed upgrade. **T 1** often times has more growth potential than DSL because it is not distant-sensitive. **T 1** has extensive and costly start-up with install of fiber lines and hardware (CSU/DSU).
Reliability	**DSL** is on a dedicated, closed circuit and therefore receives guaranteed speeds.	**T 1** is on a dedicated, closed circuit and therefore receives guaranteed speeds.

	There is a higher degree of accountability because DSL is often a single source of contact because it offers bundled services including IP.	T 1 is not distant sensitive and may have more growth potential (no contingencies on location and availability).
Cost	**DSL** has low start-up cost and per-monthly fees by existing phone line(s) utilization and minimal equipment needs. **DSL** is usually priced on a flat monthly rate with "no per-minute" charges.	**T 1** often has costly start up (line and hardware install) and per-monthly fees from line usage charges in addition to bandwidth.
Long-Term Stability	**DSL** is intended as a long-term business solution because it not only provides dedicated, high-speed access, but also bundled, value added services from a single provider on one invoice **DSL** is here to stay because it utilizes a ubiquitous infrastructure (RJ-11 jacks, copper phone wire, Class 5 switches and data backbones). **DSL** can potentially replace or augment other existing services (T1, dial-up, ISDN).	**T 1** will most likely be a long-term business solution because it has superior market confidence from long history of proven performance and boundless availability/accessibility.
Accessibility	**DSL** utilizes existing	**T1** has boundless availability/

	ubiquitous infrastructure (RJ-11 jacks, copper phone wire, Class 5 Switches, data backbones) and thus dramatically enhances the likelihood of present service availability. **DSL** has greater exponential growth compared to rival technologies (Cable) due to wide range of coverage from CO implementation. **DSL** is most likely to be available in commercial areas because DSL providers purposely target regions with a high density in businesses and phone lines.	accessibility and consequently is not inhibited by technological, geographical or political barriers that rivals cannot match.

8.3 Configuration Steps of the Computer SPP

The first step in using the SPP is to identify its base address. The base address can generally be found in the Windows device manager under the resources for the SPP.

For Windows NT/2000 [160]:

1. On the PC desktop, right-click on My Computer and select Properties.

2. Select the Hardware tab and click on the Device Manager button.

3. Under Ports (COM & LPT) double click on the LPT1.

4. Next, select the Resources tab and the address should appear next to Input/Output Range. Figure 1 will appear on the PC screen.
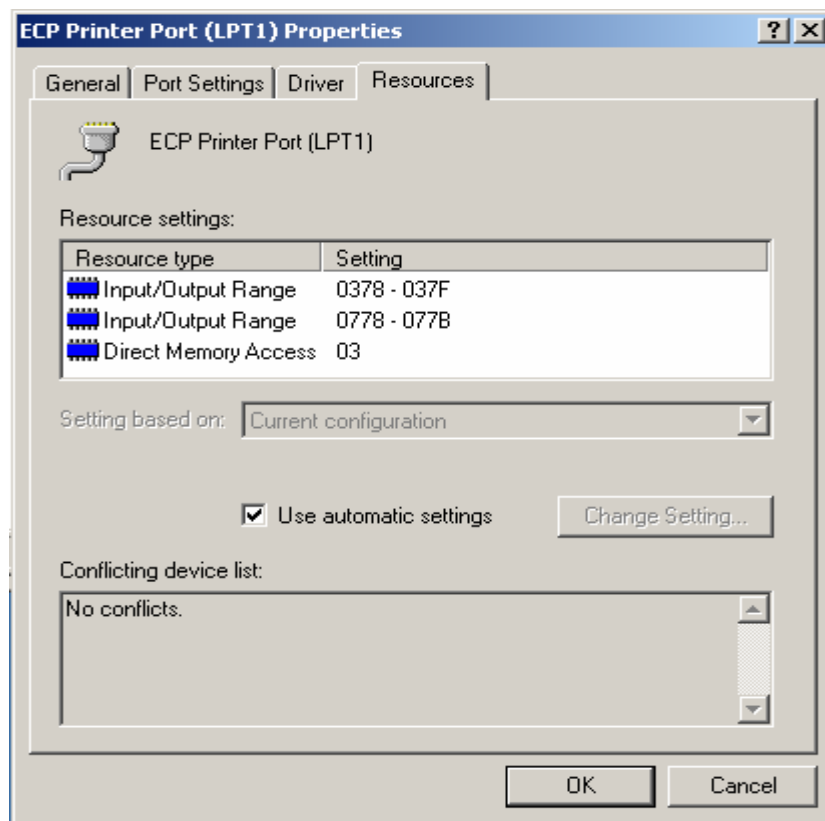
Figure 8-1 Parallel Port (LPT1) Properties in the Windows Device Manager

The base address is generally hex address 278, 378, or 3BC. There are several registers associated with the SPP but for purposes of simple output we only need to concern ourselves with the Data register. This is the first register in the I/O range, and so is located at the base address. In the computer being used for this study, the base address is 378.

8.4 Remote Operation Steps of the Research Test-Rig

To run the research test-rig from a remote location, the user has to follow the below given steps:

1. Ensure the test-rig apparatus are connected and energised and the local computer is ONN.

2. Install the LabVIEW Real-Time Engine file into the client computer. This file is provided for free of charge from the NI website.

3. From a standard web-browser, Type the following URL: http://bauhaus.ece.curtin.edu.au/~shoailis on the address bar of the web browser on the remote computer.

4. Enter the provided username and the password. Upon entering these two, the remote user will be redirected to the program location on the local computer (server).

5. On the program main front-panel, specify and configure the addresses of both the serial and the SPP ports. The serial port is (0) for the NANOVIP Plus and (3) for the Load cell. The SPP address is 378 for the local computer used inside the laboratory.

6. Enter the ASCII for the NANOVIP Plus which is (:010302020015E3) [116].

7. Specify and configure the DAQ card parameters as follow: (device: 1, counter: 0, time base: 100 KHz, measurement type: measure period).

8. Open a new file to save the measurement data for off-line analysis and future reference.

9. Press the START button on the IM main panel board shown in Figure 4-7 in this report.

10. Energise the different M&T instruments.

11. Press the run icon on the program front panel. It is the arrow located on the top left corner on the front panel in Figure 4-5 in this report. This will switch the program to the run mode.

12. To energise the system, press the SIS on the program front panel. This replaces the SIS in the IM side shown in Figure 4-7 in this report. This switch connects the IM to the external power supply. By this step, the user should be able to see different readings of the system parameters on the program front panel.

13. To connect the load bank with the IM, LIS has to be switched. This switch

replaces the SIS in the DC-Dynamometer front panel shown in Figure 4-8 in this report. After that, and depending on how much load is required, loads controllers (L1-L5) can be switched ONN and OFF. The changing on the load amount varies the system parameters reading. These readings will be presented on the table.

14 To stop the running of the test-rig, press the STOP switches. First switch stops the running of the sub-VI that measures the IM speed; the second switch stops the sub-VI that controls the SPP. After these two switches were pressed to OFF position, user has to wait until the reading of the parameters (V, I, P, pf, Speed) on the meters returned back to zero position or closer on the meters and then the switch number three can be pressed to stop the running of the entire program. Following to that, and if the file for saving data has not been specified, a screen to open a file where the measurement data can be saved will pop up and there the data file can be specified. Furthermore, the relation between some of the system parameters will be plotted on the graph plotter. The file can be opened from the normal Excel program as it is shown in Figure 4-12 in this report.

8.5   Root-Locus Plot of the System with the Time-Delays

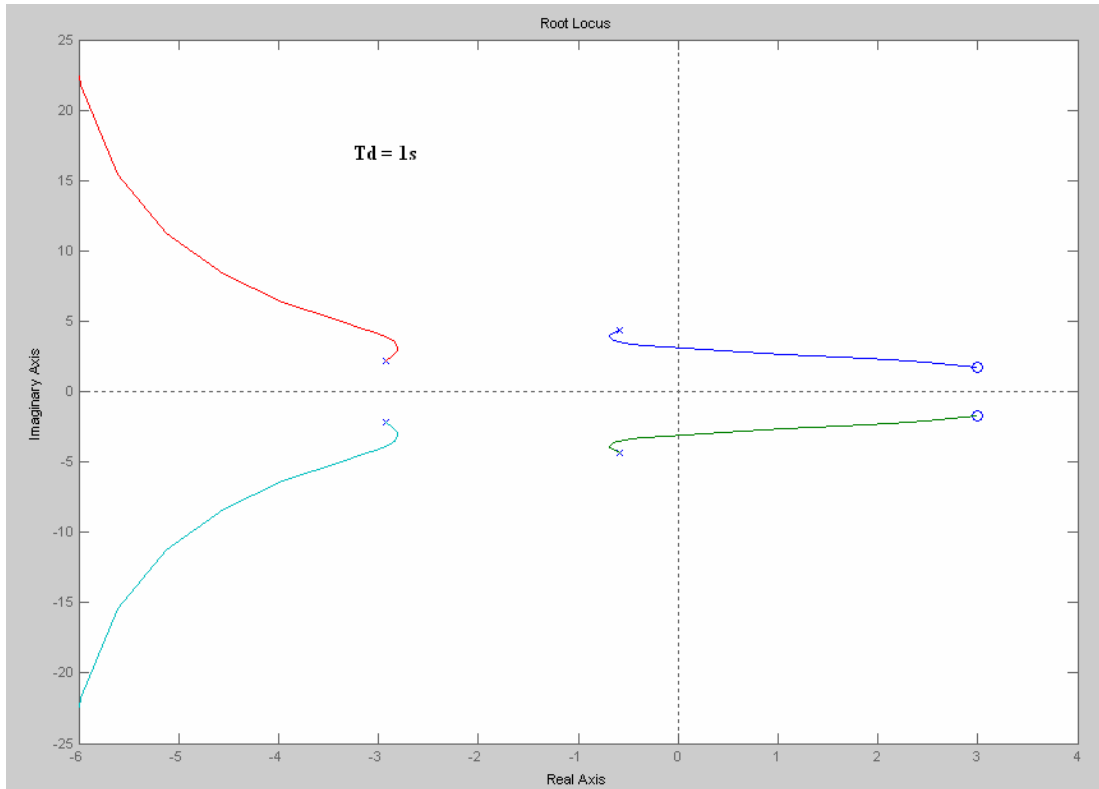
Figure 8-2 Root-locus for the system with 1s time-delays

Figure 8-3 Root-locus for the system with 1.5s time-delays
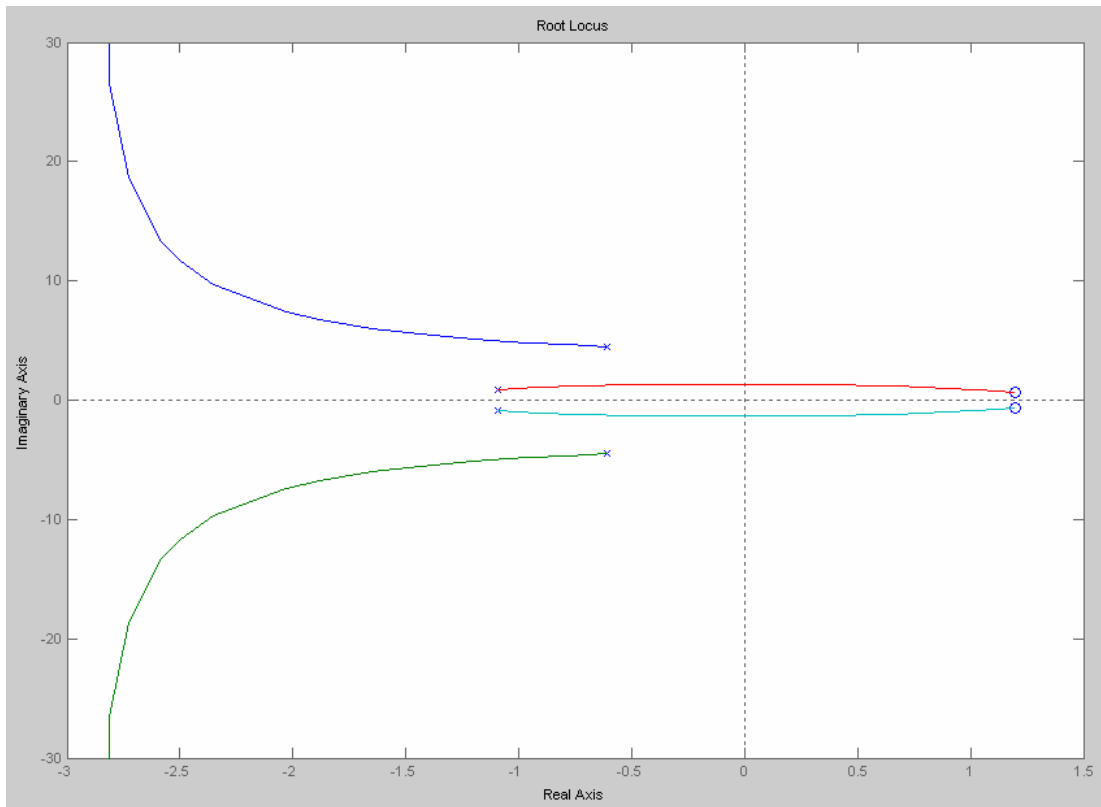
Figure 8-4 Root-locus for the system with 2.5s time-delays
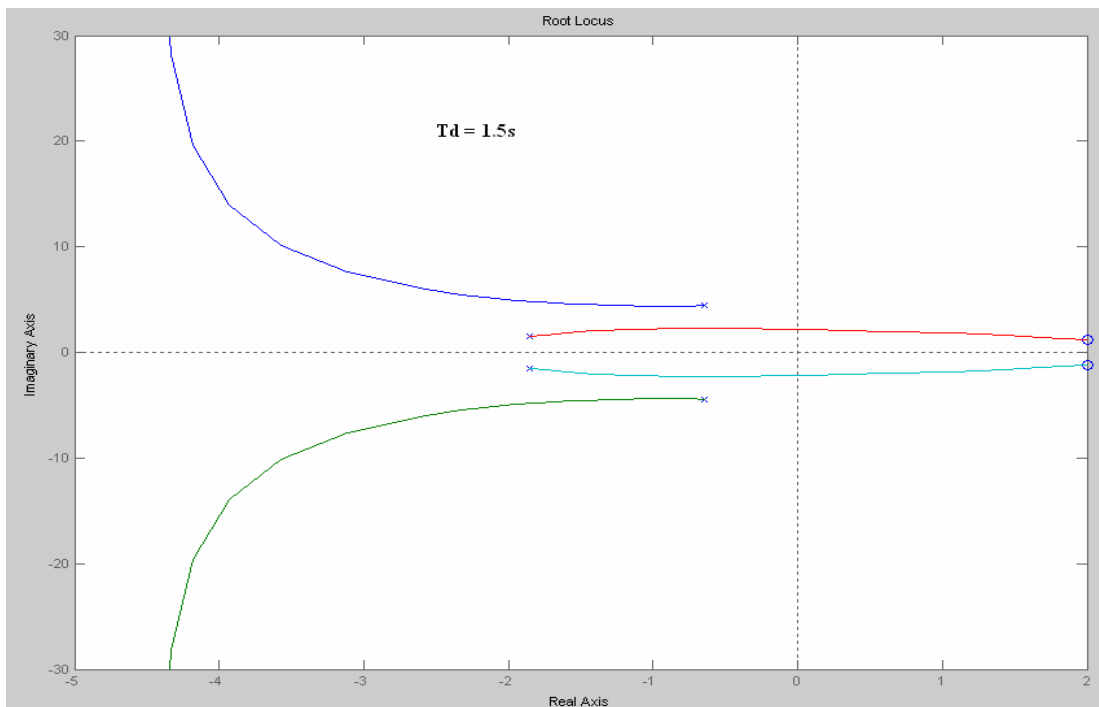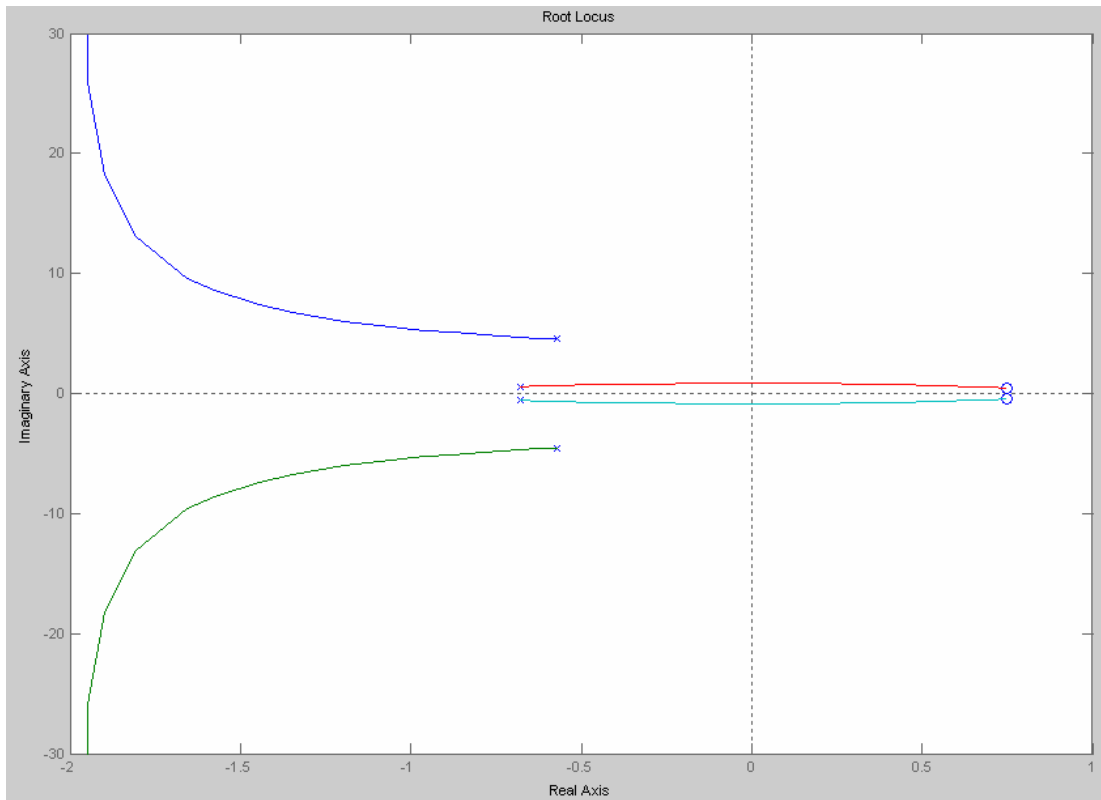

Figure 8-5 Root-locus for the system with 4s time-delays

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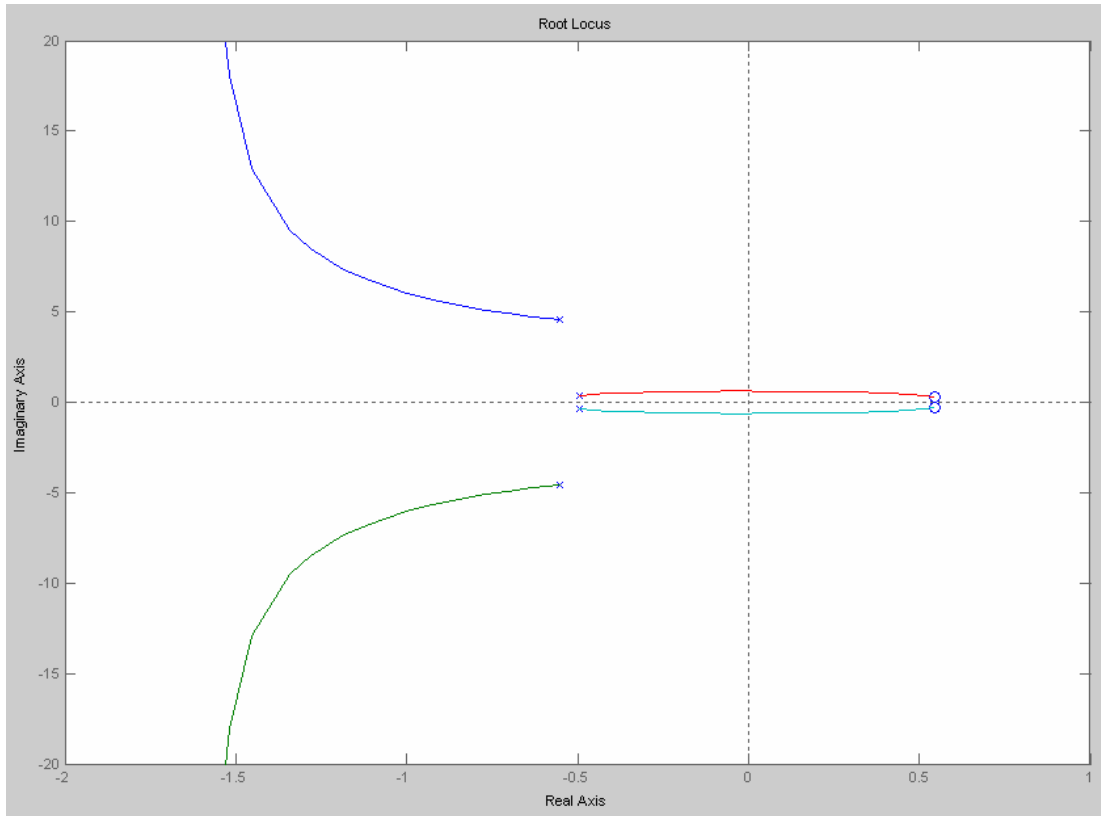
Figure 8-6 Root-locus for the system with 5.5s time-delays
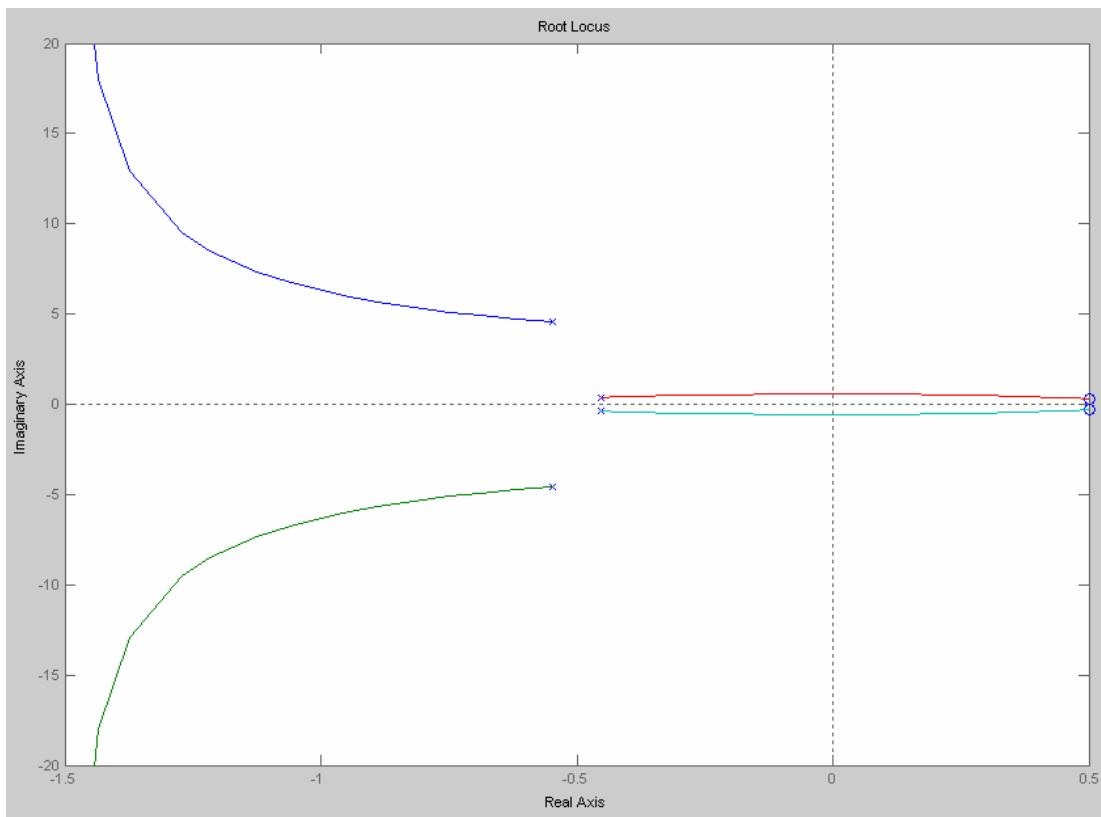
Figure 8-7 Root-locus for the system with 6s time-delays

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8.6 Matlab Program that Develop the System Poles, Zeroes and CLTF with the Time-Delays

In this program, and as it has been stated in the report, the the second order equation of the Pade approximation for the time-delays has been used.

```
function CLTF with time-delays
a=1;
b=1 1 20;
G=tf(a,b)
s=feedback(G,1)
P=pole(s)
Z=zero(s)
t=0:0.5:6
for i=1:length(t)
tvec=t(i)
num=tvec^2 -6*tvec 12;
den=tvec^2 +6*tvec 12;
S=tf(num,den);
n=series(S,G);
m=feedback(n,1)
Pd=pole(m)
Zd=zero(m)
figure (i)
clf
step(m)
rlocus(m)
end
```

8.7 Matlab Program that Analyse the System during the Transient States

```matlab
function the System during the Jump States
T=0:0.5:25;
t=0:2:6
U=zeros(size(T));
U1=ones(size(T));
z=1;
q=1 1 20;
G=tf(z,q);
num=z*q;
den=(1+num);
s=num/den
h=[0]
for i=1:length(t)
    tvec=t(i);
    x1=h(end)
    if  (tvec==0)
        x0=[x1 x1]
        [u,i,j,p]=tf2ss(z,q)
        o=lsim(u,i,j,p,U1,T,x0);
        h=[h;o];
    elseif ( tvec==2)
        x0=[x1 x1 x1 x1]
        f=[0 0 4 -12 12];
        v=[4 16 108 240 252];
        L=tf(f,v);
        [a,b,c,d]=tf2ss(f,v)
        k=lsim(a,b,c,d,U1,T,x0);
        h=[h;k];
    elseif (tvec==4)
        x0=[x1 x1 x1 x1]
        f=[0 0 16 -24 12];
```

```
        v=[16 40 372 468 252];

        L=tf(f,v);

        [a,b,c,d]=tf2ss(f,v)

        k=lsim(a,b,c,d,U1,T,x0);

        h=[h;k];

    elseif (tvec==8)

        x0=[x1 x1]

        [u,i,j,p]=tf2ss(z,q)

        o=lsim(u,i,j,p,U,T,x0);

        h=[h;o];

    else

        x0=[x1 x1]

        [u,i,j,p]=tf2ss(z,q)

        o=lsim(u,i,j,p,U,T,x0);

        h=[h;o];

    end

end

figure(1)

clf

plot(h),title('System  Simulation  during  the  Jumping
States'),   xlabel('Sampling   time'),   ylabel('System
Response')
```

8.8 The Flow Chart Showing the Execution steps of the Matlab Program

A. Define these variables

System TF variables

System Input
1. One
2. Zero

System Initial
Conditions = the final value of the previous state

1. Sampling time
2. Time Delay Variables
$T_d = 0: 0.5:6$

B. Find the CLTF of the system for each time delay T_d value.

C. Run a value of T_d & check the following conditions:

Is $T_d = 0$s — **YeS**

No

1. Check the system Initial conditions
2. Find the state space equation of the CL system.
3. Simulate the system for the given input.
4. Plot the simulation.
5. Update the system initial conditions.
6. Go to step C

Is $T_d = 0.5$s — **Yes**

No

1. Check the system Initial conditions.
2. Find the state space equation of the CL system.
3. Simulate the system for the given input.
4. Plot the simulation.
5. Update the system initial conditions.
6. Go to step C

Is the server is opened, T_d out of the range — **Yes**

No

1. Check the system Initial conditions.
2. Find the state space equation of the OL system.
3. Simulate the system for the given input.
4. Plot the simulation.
5. Update the system initial conditions.
6. Go to step C

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D. Repeat theses steps for all values of T_d. When the Td values finished, plot the individual response on a single graph and end the program**.**