Journal of the Korean Institute of Illuminating and Electrical Installation Engineers (2012) 26(10) : 60~71 논문 26-10-8
http://dx.doi.org/10.5207/JIEIE.2012.26.10.060 ISSN 1229-4691(Print) ISSN 2287-5034(Online)

Design of Multi-protocol IED for Networked Control System of Multi-Induction Motor in Industrial Fields

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Abstract

This paper proposes a new design and implementation of multi-protocol IED for networked control system of multi-induction motor in industrial fields. The experimental multi-induction motor based multi-protocol IED of Modbus/LonTalks/TCP/IP module is designed and fabricated. This article addresses issues in architecture of LonWorks/Ethernet sever, embedded processors architecture for converting Modbus protocol to LonTalks protocol, integrating preconfigured software, and Internet technologies. It is also verified that the multi-induction motor control and monitoring system using LonWorks/Ethernet server have available, interoperable, reliable performance characteristics from the experimental results, especially, the seamless integration of TCP/IP networks with control networks allows access to any control point from anywhere. Thus, the results provide available technical data for remote distributed motor control system of industrial field or building microgrid with LonWorks BAS.

Key Words : Multi-Induction Motor Control, LonWorks/Ethernet Server, Modbus Protocol, MIP/DPS, TMS230C32 DSP, and Networked Control System, Multi-Protocol IED

1. Introduction

LonWorks network developed from Echelon Co. is a complete system that incorporates a communication standard with ANSI/EIA 709.1[1-2]. It also includes management and control. LonWorks technology has become so prevalent in building and process control systems that it has open, multi-vendor control systems. LonWorks can support large-scale fieldbus network using multiple media with peer-to-peer and master & slave architecture. Now, distributed architectures based on smart component and fieldbus technologies are becoming more common in modern control system. They replace the controller-to-sensor current (4 to 20mA) or voltage loop connections by digital, bidirectional, multi-drop serial bus communications. Field compatible field devices become so-called “smart” devices, capable of executing simple control, diagnostic and maintenance functions and providing

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Date of submit : 2012. 4. 24
First assessment : 2012. 5. 18
Completion of assessment : 2012. 9. 18

bidirectional serial communication to higher level controllers[3].

The integration of intelligent device, device-level networks (fieldbus), high performance control and estimation technology, and software into motor-control systems can deliver efficient operation and management, improved diagnostics, early warnings for increased system reliability, design flexibility, and simplified wiring. Also, remote access to motor-control information also affords an opportunity for reduced exposure to hazardous voltage and improved personnel safety during startup and troubleshooting [4]. Now a day, in case of the control of power converter and power electronic systems, the intelligent devices, that is, smart motor control center is required to control and manage motor system efficiently and reliably. The three major components of a Smart MCC include the MCC structure with built-in communication media, intelligent motor control component and smart MCC monitoring software and documentation. The goal of integrating these components is to make the smart MCC easy to install and maintain without intensive training or local expertise because of providing plug-and-play set-up and monitoring of real time data as well as trending, component history and spare part information. Device-level integration through digital communication is the key to unlocking the full potential in the electronic power controls being installed in industrial plant today. Therefore, it is the important technology to develop the networked intelligent motor-control systems and the intelligent motor driving control system in the industrial field including the large scale motor system especially. But now a day, the ordinary microprocessors are widely utilized due to cheap cost and global company, which had proprietary protocol have provided the open solution of fieldbus to control the industrial device and system.

The most feasible subject to be considered seems to be how to harmonize fieldbus with conventional DCS to work at a full potential. In this paper, we introduce LonWorks network related to multi-induction motor control for web based control. The most suitable multi-protocol IED is developed to control and monitor the multi-motor system. Therefore, it is very important to connect LonWorks network to any powerful and cheap microprocessor which was used widely in the industrial fields such Modbus and Ethernet protocol. We utilize the MIP/DSP to add the widely used microprocessor to LonWorks networks, which is provided from Echelon Co. We also describe how to develop the interface to TMS 320C32 DSP, host processor for a LonWorks device using MIP/DPS developer's Kit.

Neuron chip running the MIP/DPS communicates with host computer using dual port RAM with hardware semaphores. The LonWorks control module with a high performance is developed, which is composed of the 32 bit DSP microcontroller for host processor, the smart neuron chip for LonWorks protocol and iLon 100 for a web server[5]. This intelligent control board is verified as preceding the various function tests from experimental system with an inverter driving systems. It is also confirmed that the developed control module provides stably 0-10VDC linear signal to the input signal of inverter driving system for varying the induction motor speed. Thus, the experimental results show that the fabricating intelligent board carried out very well the various functions in the wide operating ranges of two motors drive control system. This developed control module expect to apply to industrial fields to require the comparatively exact control and monitoring such as multi-motor driving system with inverter, variable air volume system, the boost pump water supply systems and building microgrid [6-7].

2. Development Networked Intelligent Control Module with High Performance and functions

2.1 LonWorks Network

LonWorks from Echelon is a complete system that incorporates a communication standard with ANSI/EIA 709.1. It also includes management and control. The neuron chip contains three eight-bit processors. The application processor is executing user code written in a variant of Neuron C language with powerful input/output functions. A network processor handles addressing, routing, authentication of packets and the presentation of data to the application processor. The MAC processor is responsible for encoding I/O, importing measurement, calculating, calibration and transmission of packets of data to the network. Most of intelligent functions are implemented by embedded neuron networks stored in EEPROM. These two processors comply with six layers of the ISO reference model. This allows the transparent use of the network to pass information between the different programs in the application processors. LonWorks networks can be implemented the simplified interface design, multi communication medium and communication data rates, High level programming language, and providing SNVTs (Standard Network Variable Types) for interoperability by providing a well-defined interface for communication between nodes made by different manufactures

2.2 TMS320C32 DSP

The TMS320C32 is the newest member of the TMS320C3x generation of digital signal processors (DSPs) from Texas instruments. This is an enhanced 32-bit floating-point processor manufactured in 0.7-μm triple-level-meal CMOS technology. The enhancement to this processor architecture include a variable-with external - memory interface, faster instruction cycle time, power-down mode, two channel DMA(Direct Memory Access)coprocessor with configurable priorities, flexible boot loader, relocatable interrupt-vector table, and edge-or level-triggered interrupts. For the user friendly-external handling, the TMS320C32 has a configurable external-memory interface with a 24-bit address bus, a 32 bit data bus and three independent multifunction strobes. The flexibility of this unique interface enables product designers to minimize external-memory chip count.

The TMS320C32 DSP used as the host processor is left to run the application program and handle the layer 6 and 7 protocol services: network variable processing, and explicit message processing. Using these services, the DSP can easily send and receive both network variable updates and application message.

A simple network drive is implemented on the host processor to manage the interface with the MIP. The Lonworks network driver protocol defines a standard interface specification for the LonWorks network interface.

2.3 Development of intelligent master controller

In this section, the development of a LonWorks intelligent node with the high performance for the networked motor control is described to illustrate intelligent device components. Fig. 1 shows the block diagram of intelligent master control module which is developed for being used in networked intelligent motor control system, whereby five elements are involved, namely a TMP3150 Neuron chip, TMS320C32 DSP, Transceiver (FTT-10A), ROM, SRAM for DSP, PLD (EPM7084) and Dual Port Static RAM. The two CPUs is connected by the dual port static RAM. The objective of the architecture is to obtain improvements in reliability, safety at low cost and the achievement of high performance in the networked control system. These intelligent control modules were fabricated to control and monitor the inverter and motor. It can communicate bi-directionally digitalizing data between the Modbus protocol and LonTalk protocol. The Neuron Chip running the MIP/DPS communicates with the TMS32C32 DSP using a dual ported RAM with hardware semaphores. The MIP enables the attached host to implant LonWorks applications and to communicate with other devices using the LonWorks protocol. Applications on the host can send and receive network variable updates and application messages, as well as poll network variables. The TMS320C32 DSP is used to host which control, command and monitor the inverter drive and motor. The 3150 Neuron chip is utilized to communicate the LonTalk protocol to the high level Ethernet network. This significantly reduces overhead in the host since the host processor does not have to deal with lower layer network services such as media access control, collision avoidance, acknowledgements, retries, duplicate message detection, message validation, authentication, and priority processing. Fig. 2 represents the overview of intelligent master controller based on LonWorks network. Hardware of specification of intelligent master controller is shown in Table 1.

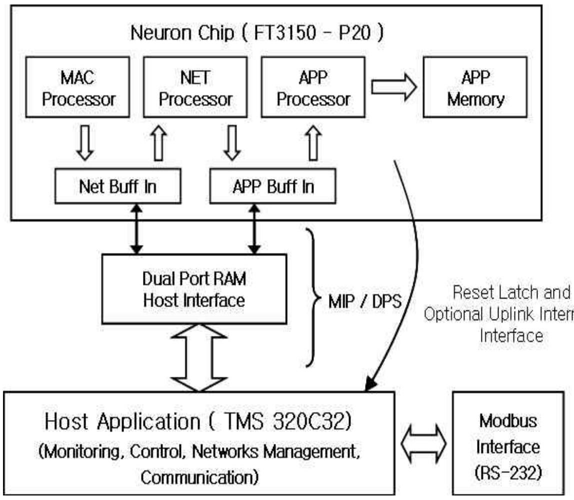

Fig. 1. Detailed block diagram of ModBus/LonTalk/TCP/IP IED

Fig. 2. Intelligent master controller based on LonWorks network

From a practical point of view, the main components of the intelligent master controller are:

- 32-bit TMS32C32 DSP for the fast execution of the control algorithms and complex logic operation. The field data for the fast processing are transmitted from the LonWorks control modules to connect I/O of multi-motor systems. After the control and command data is processed and executed, they are sent the pertinent data and information to LonWorks control modules through

Dual-port RAM. This host controller has the 512Kbit EEPROM and 4Mbit SRAM.

Table 1. Hardware of specification of intelligent master & slave controller

Host CPU	CPU Type Clock ROM Memory RAM Memory	TMS320C32PCMA50 50MHz 512k EEPROM 4Mbit SRAM(Battery Back up)
Slave CPU	CPU Type Clock ROM Memory RAM Memory	TMPN3150 10MHz 512K EEPROM None
Protocol	LonTalk	
Transceiver	FTT-10	
Power	16- 36 VDS/AC	
Microprocessor interface program	MIP/DPS Echelon	

• 8-bit microcontroller to be named Neuron Chip, which is working at 10MHz. devoted to communications and control modules with LonTalk protocol for executing delivery of data received from the host processor and commands from the Web server. This microcontroller of the TMPN3150 CPU type has the 512K EEPROM.

• Dual-port static RAM to pass information between both 8bit Neuron chip and TMS320C32 DSP to store the node state. High-speed dual-ported RAM interface sends and receives hundreds of packets per second with minimum host overhead.

• Communication networks based the LonTalk protocol between the intelligent master controller and the Web server.

• A serial RS-232 is included for 32-bit DSP microcontroller in order to make local channels possible in each node, and also to allow software updates via RS-232 for microcontroller. We get the final data processed and operated from DSP chip through RS-232 port. Further, this can use to the gateway to translate LonTalk protocol to RS-232C. RS322C is an important hardware wire to connect between the Modbus board and the host processor.

• The Transceiver

A transceiver provides the mechanical and electrical interface between the Neuron chip of the device and the communication medium. Multi-medium transceivers enable the actuator and sensors to operate in different environment.

• Microprocessor Interface Program (MIP)

The Microprocessor Interface Program is firmware for the Neuron Chip that transforms the Neuron Chip into a communications coprocessor for an attached TMS32C32 DSP. The MIP/DPS is typically used with high-performance host such as 32-bit microprocessors, but may be used with any host. The Neuron Chip running the MIP/DPS communicates with the DSP using a dual ported RAM with hardware semaphores. The network interface with the MIP handles layers 1 through 5 of the LonWorks protocol.

MIP/DPS is delivered in a Neuron C library that extends the Node builder software to include system call for the MIP. We created a short Neuron program that define the initial network configuration for the network interface and calls the MIP/DPS system function.

The Lonbuilder is created a PROM image which is programmed into a PROM using a PROM programmer.

The PROM is installed a network interface that includes a Neuron 3150 chip, dual port RAM, reset Latch, oscillator, communications transceiver. The dualport RAM must meet the memory timing specifications of the neuron 3150 Chip and must implement hardware semaphores as specified in the LonWorks MIS User's Guide. Cypress 78144 dualport RAM is used to meet these specifications in our experimental sets. The IO0 pin on the Neuron chip is used to generate an up-link interrupt.

The MIP/DPS pulse IO0 whenever packets is available for the host. The host can use this interrupt to reduce the latency of response incoming network variable update and message.

3. i.Lon 100 server

3.1 Web server

For inverter based motor control, the embedded Web server and IP router devices are used. There are various types of IP routers providing embedded Web servers, In this case, the IP router play two roles:

(1) Router- provides connection between LonWorks control network and IP data network;

(2) Web server- provides access to the variables on control devices and makes them available through standard Web browsers.

The applications of embedded Web server are main issues to be concerned in this approach, while the function of router is used to integrate the control networks and Internet/intranet. The embedded Web, accessible by a standard Web browser, serves the Web pages that refer to the motor control variables. The embedded Web server has been extended with HTML tag definitions, providing the functions which meet needs for data exchange between the control networks and sever, incorporating the motor variables to HTML Tags. In extended Web server, to return a Web page to a browser, the Web server explains the Web pages, find out the special extended HTML tags and indicates a network variable reference. The Web server substitutes the current value of a motor variable for the tags when returning the information to the browser.

By extending the HTML tags only, the Web pages are compatible with standard Web pages and can be written using common editing tools. When embedded Web server is used, it is easy to access the control devices in the control networks. To display the network variable by a browser, one need to write the correct HTML tags in the display places only. Using the embedded Web server, the program to access control network is easy to develop. However, the function and capability of the embedded Web server provided are limited due to the price and market needs. In particular, the graphic user interfaces for Web browser need large memory space to store graphic files. It is not practical to use the embedded Web server.

3.2 i.Lon 100 Web server

LonWorks and TCP/IP router provides a seamless transparent connection to LonWorks networks segments to an Ethernet or wide-area backbone networks. Such a unified network can significantly reduce the life cycle cost of the system and can enable to new functionality by taking advantage of IP technology of the Web and Internet.

To connect LonWorks based everyday devices to the Internet, a LAN or a WAN, the i.LON 100 Internet server is used. This allows a service center to configure, monitor, and control everyday devices from across the room, or across the globe. The i.LON 100's software applications provide a rich set of functions that enable it to work as a self-contained controller without the need for a PC or host processor. Standard application includes scheduling, data logging, alarm detection & dispatch, and meter reading. The i.LON 100 applications are accessible from web pages, SOAP/XML, or via standard LNS plug-ins. The free topology twisted pair interface uses in expensive twisted pair wiring to interconnect devices without regard to wiring topology: the installer id free to route the wire in the most expeditious manner. The 10/100 Base T interface provides connection to a local Ethernet network and also supports a built-in web server and SOAP server. The i.LON 100 e-mail client is used to send e-mail dispatches of alarm conditions and data log content. The combination of web and SOAP servers enables the creation of web browser-based interfaces as well as connectivity to enterprise system such as manufacturing, accounting, and SCADA application. All information is provided in ether HTML or XML formats. This server is designed for use in both local and wide area networks, and is compatible with the most popular IP networking protocol TCP, STMP, SNTP, ICMP, FTP, DNS and so on. . Regardless of whether one is connecting to a LAN, WAN, or ANSI 709.1 protocol based system, the i.LON 100 offers interoperable networking based on open standards [8-9].

4. Implementation of Experimental system

4.1 Networked control system for web based multi-motor systems

Integration of control network and data network can be usefully realized not only the easy control execution in the web browsers but also the positional and speed information and further fault detections signal in the motor drive system of industrial field .

Vector inverter control system manufactured in LS industrial Co. provides several network boards such as Modbus, F-net, DeviceNet and Profibus. Modbus protocol is popularly used in motor drive control system. To connect the inverter with Modbus protocol board to LonWorks network, the intelligent master controller is designed and fabricated to experiment networked intelligent motor control as shown in Fig. 3. The configuration of experimental system is shown in Fig. 3. This new Lon-gateway converters the Modbus protocol to LonTalk protocol. The developed intelligent master controller has the RS-232C port to connect the RS-232C port of the inverter Modbus board. This system consists of the two inverter with Modbus protocol, intelligent master controller, Web server for Web based-control and PC for motor operational commanding and monitoring and two encoders to sense the motor speed. The speed control of motor is transmitted to the i.Lon server through at first PC connected to Ethernet. Then, i.Lon server gives the motor speed commanding data to a Lon-Gateway1 which have the network variables of LonWorks network. In this case, Lon-gateway1 communicates bi-directionally with the Modbus protocol board of the inverter. The exchange between the Lon-Gateway1 and the motor drive control system with control data tags correspond to one to one in the networks variables of LonWorks. In operating the motors, completely digitalized packet data are used. This concept is different from that of analogy signal. The encoder is used to sense a speed of master motor. The sensed data is delivered to the AO port of i.Lon server. It transmits the commanding motor speed data to the Lon-Gateway2 and then the intelligent slave controller give finally the commanding data to motor drive system played a slave role. Therefore, this experimental system is configured to test the fileldbus based motor control and Web based motor control system. The manually manipulated function is also added.

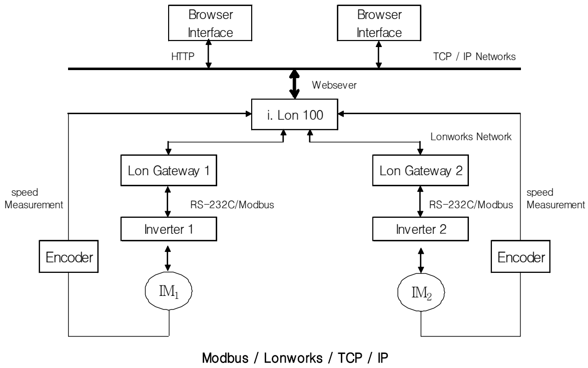

Fig. 3. Configuration of networked control system for web based multi-motor systems

4.2 Hardware configuration for experimental system

The integration systems for testing the performance of a novel proposed networked intelligent motor control system are implemented. The configurative components are included two motor drive systems with vector control function, two Lon Gateway, two encoders, two induction motors and command and Web based monitoring system. The inverters were fabricated by LS Industrial Co. The open loop and closed loop control of these inverters can be selected by the function options to be provided at the manufacturer. Fig. 4 represents the overview of experimental system for the networked intelligent induction motor control system. The photography of inverter system for induction motor drive is shown in right side and also Modbus -RTU option board is included. This option board consists of the 8bit CPU, DPRAM, ROM and power supply. Fig. 5 shows the control modules to be designed and fabricated for verifying the networked motor control logic and algorithms. They include the i.Lon server, two Lon-Gateways, DIO (Digital Input/Output) LonWorks module, AO (analogy output) LonWorks module. The i.Lon server is obtained by Echelon Company. The others are designed and installed by our laboratory. Fig. 6 represents the view of encoders installed in the motor shaft to detect the motor speed. The specifications of the induction motor, motor drive

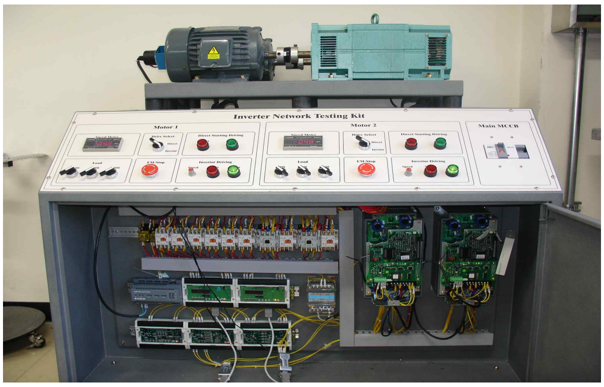

Fig. 4. Overview of experimental system

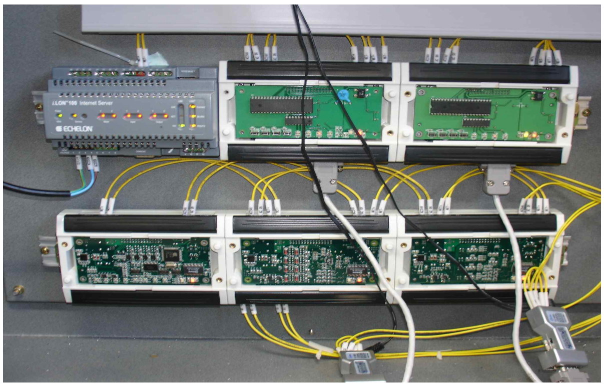

Fig. 5. Control modules

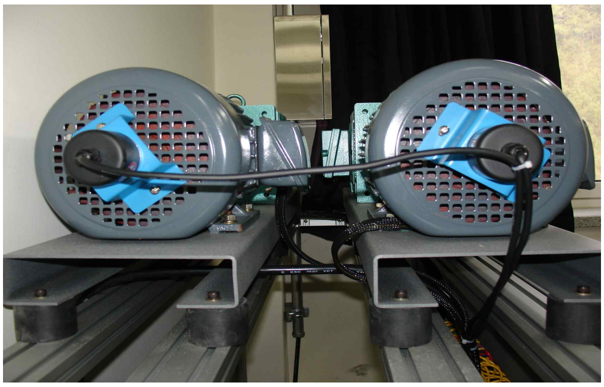

Fig. 6. View of encoder installation

system, encoders and Modbus-RTU are shown in table 2.

Table 2. Induction motor specification

Power [kW]	1.5
Frequency[Hz]	60
Voltage[V] (△/Y)	220/380
Current [A]	3
Speed [rpm]	1800
Pole pair	2

4.3 Software configuration of intelligent motor control for experimental system

In an intelligent MCC, every motor-control unit related to the process must have communication capability. Ideally, all the MCC units should also have input points to monitor devices, like the disconnect switch, contactor, overload relay, or hand-off-auto elector switch. The two basic types of devices that form the core of a networked MCC are intelligent overload relays and miniature distributed input-output (I/O) block. This intelligent MCC receive the data and information on the inverter and IM from RS 232C through the Modbus board. The important data include current monitoring, protective functions, programmable parameters for the protective functions and diagnostics of time to overload trip/reset and history of trips. This intelligent master controller communicates bi-directionally between master controller and Modbus board. The data exchange was carried out by the one-to-one way such as the network variable of master controller corresponding to the Tag of Modbus. Therefore, the total data of Modbus board gathered from inverter controller and the induction motor can be delivered to the intelligent master controller namely intelligent MCC. The motor drive system is set to the slave and then the intelligent master controller is also fixed to the master. In the control level, the command information is given by network variable inputs of LonWorks network and the conditioning and monitoring data from Modbus is given to the network variable output. The important software configuration is summarized as followings.

Intelligent Overload Relay

The most common device in an intelligent MCC is a motor starter incorporating a solid-state overload relay. Features available in this intelligent overload relay include:

- Built-in network communication
- Input points for monitoring disconnect or selector switch
- Output points for controlling the contractor
- LED for status indication
- Protective functions: thermal overload, underload, jam, current imbalance, stall, phase loss, and zero sequence ground fault.
- Programmable parameters for the protective functions: trip level, warning level, time delay, and inhibit window.
- Current monitoring: Phase, average, percent full load, ground fault, imbalance, and thermal capacity.
- Diagnostics: time to overload trip/reset and history of trips.

Minimum Distributed I/O Blocks

Disconnects, circuit breakers, and non-intelligent starters have no means to communicate directly with networks. A distributed I/O block within the unit can link these devices to the network. The I/O block must have an adequate number of input and outputs but be small enough so that the MCC unit size is not altered. Four inputs and two outputs satisfy most motor-starter applications, since this allows monitoring of the contactor, disconnect, overload-relay auxiliary contact, and, if present, hand-off-auto selector switch.

Preconfigured Monitoring Software

To integrate the intelligent MCC hardware elements and deliver useful real-time information with minimal expense and efforts, a preconfigured monitoring software package offers an effective solution. This MCC software eliminates costly customized MCC screens within operator interface software, yielding a plug-and-play solution.

Integrated Electronic Documentation

Good documentation is necessary for efficient startup and troubleshooting, but the documentation is either incomplete or misplaced altogether. In the case of the intelligent MCC, electronic documentation can be accessed on the same PC running the monitoring software. This allows the users not only to view the real status of the MCC but also to view computer aided design drawings, user manuals, and spare parts information applicable to specific MCC units.

5. Experimental results and discussions

Fig. 7 shows the block diagram for configuring the networked intelligent motor system to show the experiment sequence including Web server. The Lon GWMF represents the intelligent master controller which connects to Web server i.Lon 100 in high level network. We carried out the various experiments on the networked based the wide-range motor speed control. At first, the wide range motor speed control is taken an experiment for tracking the slave motor speed to be commanded from the master motor speed. The sequence of this experiment is taken steps as next procedure. For the first time, The Web server is received the speed commend from the Web browser of PC connected to intranet and Internet. Then, the i.Lon100 web server gives the command to the intelligent master controller, namely, Lon GWMF of Fig. 8. This host processor of master Lon GWMF conveys the motor speed information to Modbus board of the motor drive system through the RS-232C. Finally, the master motor speed is changed by inverter. Lon GWMF of master side give this master motor speed information to the slave Lon GWMF through LonWorks network. The same sequence carried out in the master is preceded in the slave side. In the end, we can carry out the motor speed tracking experiments of the networked intelligent motor control system.

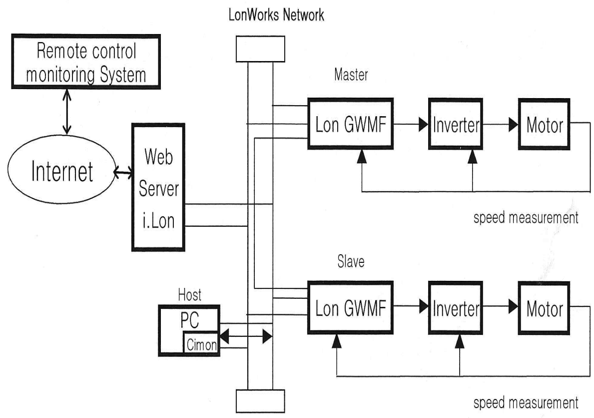

Fig. 7. Block diagram oriented networked control system

The experimental results were implemented to display in the Web page of the browser. The all experimental data and monitoring data is sent to the Web server developed by Echelon company.

Fig. 8 shows the tracking experimental results. The curve of motor A represents the varied motor speed curve controlled by the master Lon GWMF. The curve of motor B in Fig. 9 also means the varied motor speed curve controlled by the slave Lon GWMF.

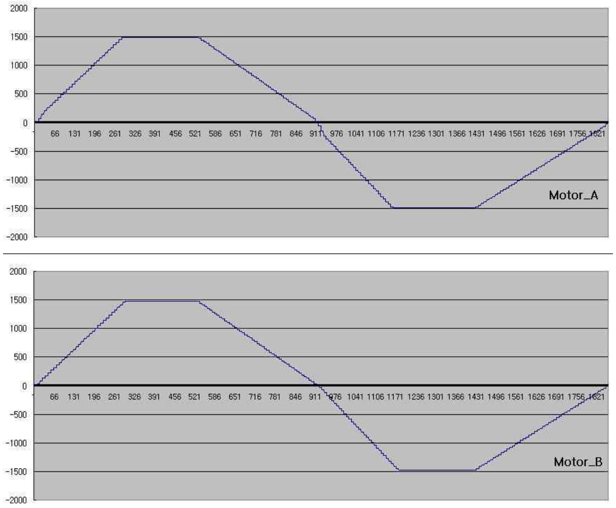

Fig. 8. Tracking experimental results of three step motor speed variation

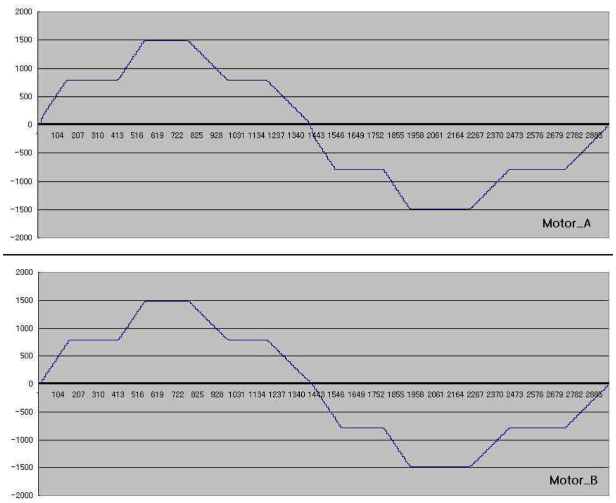

Fig. 9. Tracking experimental results of five step motor variation

When we compare with two experimental resultant curves, these results show the good tracking performance of the intelligent master and slave controller. Fig. 9 shows the five step motor speed variations in forward direction. The good results were obtained from the networked intelligent motor speed and position control experiments. It is confirmed the new proposed networked intelligent control system is very reliable and robust from the experimental smart results without time delay and communication noise. The motor speed data and position data is detected by encoders installed in the induction motor shafts respectively and then the data was transmitted to the Web server.

6. Conclusions

This paper presented the new architecture of networked intelligent control system using the smart MCC and Multi-protocol IED for reliable operation of multi-induction motor. The intelligent master controller was designed and implemented to operate the multi-motor system effectively and reliably. The compact integration of the control and data network is also configured.

An experimental system was configured for verification of the developed fieldbus control module and integration methods of control and data networks for control and monitor multi-motor system. The main results of the proposed networked intelligent control system, intelligent master controller, integrated Web based control and software systems to implement algorithms suggest the following findings:

- The novel integrated architecture is flexible and reliable.
- A compact and economical intelligent master controller allows easier installation, connection of multi-vendor devices and the perfect digital data exchange.
- New integrated architecture can link easily with TCP/IP-based industrial network

The author expects to continue the study on issues related to integration this system with existing legacy control and communication performance analysis for reliable network configuration for building Microgrid management with BAS and BEMS.

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Biography

Won-Pyo Hong

Won-Pyo Hong was born in Daejeon city in the Republic of Korea, on May 15, 1956. He received the B.S. degree from the electrical engineering from the Sungsil University, Seoul Korea, in 1978 and M.Sc. and Ph.D. degrees in electrical engineering from Seoul National University, Seoul, Korea, in 1980 and 1989, respectively. From 1980 to 1993, he was senior researcher of the Korea Electric Power Research Institute at the Korea Electric Power Cooperation. He was visiting professor at the UBC, Canada, from 2007 to 2008. He is a professor at the department of Building Services Engineering of Hanbat National University, where He has taught since 1993. His main research interests are building energy management system, smart green buildings and energy system, fieldbus based control and distributed energy resources.