Development of Monitoring and Control System of Utility-Pipe Conduit (Power Tunnel) using PLC

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Abstract: The existing monitoring and control systems of utility-pipe conduit (power tunnel, cable tunnel etc) have established communication lines using optical fiber, leaky coaxial cable (LCX), and several kinds of control cable. Due to the properties of the used media, the cost of equipment is considerably high and the maintenance of the system is difficult. Also, the term of carrying out is long so that the extension of the system is in difficulty. Now it is desirable to adopt Power Line Communication (hereinafter, PLC) technology in the monitoring and control systems and use the existing low-voltage power-line for lamplight as communication line. This will lead the reduction of the construction cost and the easy maintenance of the system.

In this paper, we research the characteristics of PLC in conduit, design and manufacture the field test system, and analyze the performance of the system by field test. Then, we introduce the reliable monitoring and control system of utility-pipe conduit using PLC.

Keywords: PLC, conduit, monitoring system, VoIP, web camera, RTU, RCU, CCU, DNP

1. INTRODUCTION

The long distance utility-pipe conduit employing power cable is increasing to improve reliability and capacity of power supply. But it is difficult to maintain safety of conduit on account of its poor environment (temperature, humidity, poisonous and explosive gas, etc) and poor communication. Therefore, it is necessary to develop telecommunication system that used to manage safety, maintenance, operation, and facility protection of conduit efficiently and (remote) supervisory control system that used to check status of various facilities and control them in order to nip possible accidents in the bud. However, because the existing monitoring and control systems of conduit use optical fiber, leaky coaxial cable (LCX), and several kinds of control cable to establish communication lines, the construction needs much time and cost. It is also difficult to maintain and repair the system so that the extension of the system is hard. So, the systems in conduits has been usually monitored and controlled by man. This situation requests more efficient monitoring and control system in conduit that will not use the existing cables but power-lines as communication lines.

In this study, we designed the test system by investigating the characteristics of power-line communication (PLC) in utility-pipe conduit. Then, we tested and analyzed the performance through field verification. Based on the results, we developed the reliable monitoring and control system of utility-pipe conduit using PLC.

First, PLC modem for multimedia service as well as simple supervisory and operation has been developed, and the modem is possible for broadband data transmission. Moreover, high and low speed PLC modem has been also developed for data transmission of several facilities.

Second, we investigated and analyzed all kinds of protocols to design the communication protocol suitable to the underground conduit. As a result, the reliable DNP protocol was optimized to the utility-pipe conduit.

Third, we developed the PLC repeater for data compensation caused by noise and attenuation and the RCU (Remote Concentrator Unit) for effective communication channel operation.

Fourth, RTU (Remote Terminal Unit) and interface were developed for collection information from supervisory sensor and control of on-the-spot facilities.

Finally, we developed IP-based web camera, DVR (Digital Video Recorder) and IP-Phone applying high speed PLC for monitoring entrances, image supervisory of main facilities and telecommunication.

We installed the field test system using PLC in power tunnel, and tested the performance of the communication characteristics and functions. In this paper, we introduce the results of an efficiency test and analysis on the test system using PLC.

2. BASIC ARCHITECTURE

The monitoring system in conduit consists of three parts on a large scale. They are the long distance underground PLC network and devices, local stations, and the central monitoring and control server in main station (MS).

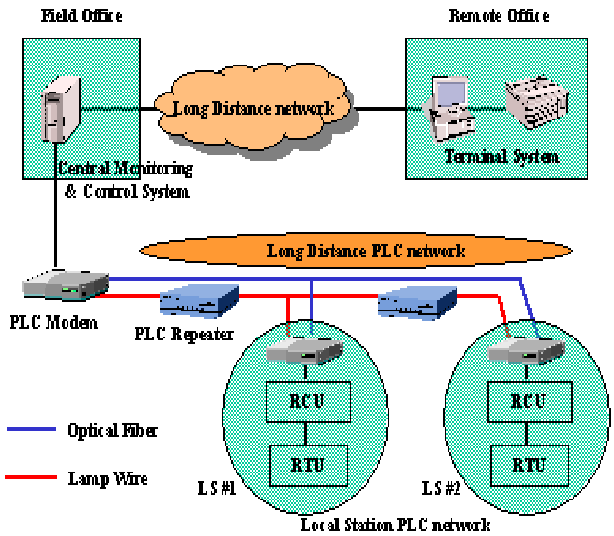

Fig. 1 The basic structure of monitoring and control system in utility-pipe conduit

2.1 Underground long-distance PLC network

Low-voltage lamp wire and two-layer structure using both high-speed PLC and low-speed PLC construct the long distance PLC network in conduit. High-speed PLC is used in long distance communication channel and low-speed PLC in local channel within local stations. It can be that periodical traffic load for monitoring devices between RTUs is separated, and that total traffic load on communication network is reduced. As a result, VoIP voice traffic and image traffic on high-speed PLC network can be transmitted smoothly. Also, RCU in local station can transmit frequently packets for monitoring and checking RTUs' states, which improves the reliability of monitoring and control system. The optical fiber in fig. 1 is used as backup line in an emergency.

2.2 Local station (LS)

LS is located in each air hole in utility-pipe conduit, and several kinds of monitoring and control sensors including entrance monitoring sensor are installed in LS. Fig. 2 demonstrates the structure of LS.

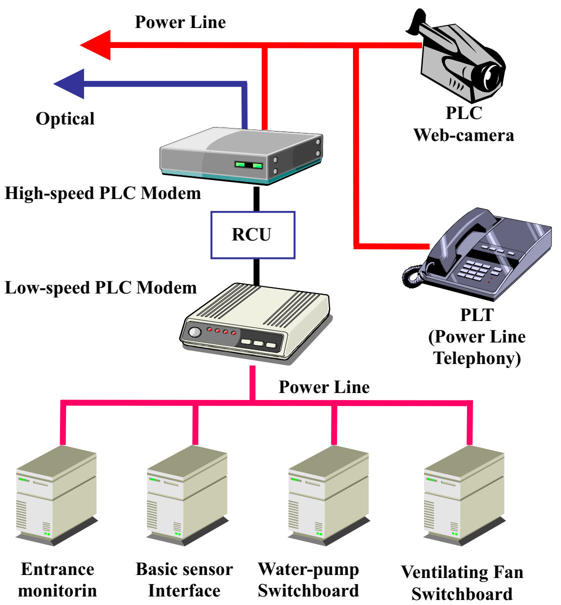

Fig. 2 The structure of local station

The control packets from monitoring and control system through high-speed PLC channel are transmitted to RCU and then modified into the format suitable for low-speed PLC channel before being transmitted to the corresponding RTU. The RTU analyzes the received packets and inputs control signal to the control panel for its corresponding device to operate following control signal. RCU communicates periodically with RTU by its own scheduling processor in order to monitor devices' states, and transmits periodically the collected information to the central monitoring and control server through high-speed PLC channel.

2.3 Central monitoring and control system

A variety of input / output terminal and server are installed in field office so that we can grasp main devices' states within conduit. The main servers are the server to monitor and control water pump and ventilating fan, the VoIP server and gatekeeper for voice communication, and the DVR server to store and manage image-sensing data. Our servers designed in this study operate on TCP/IP based environment and it is possible to connect to the system and grasp the total system operation situation in remote office through Intranet.

3. DESIGN AND MANUFACTURE OF FIELD TEST SYSTEM

3.1 Monitoring and control system in conduit

In fig. 3, monitoring and control system designed suitably for Kang-Dong utility-pipe conduit in Seoul is shown.

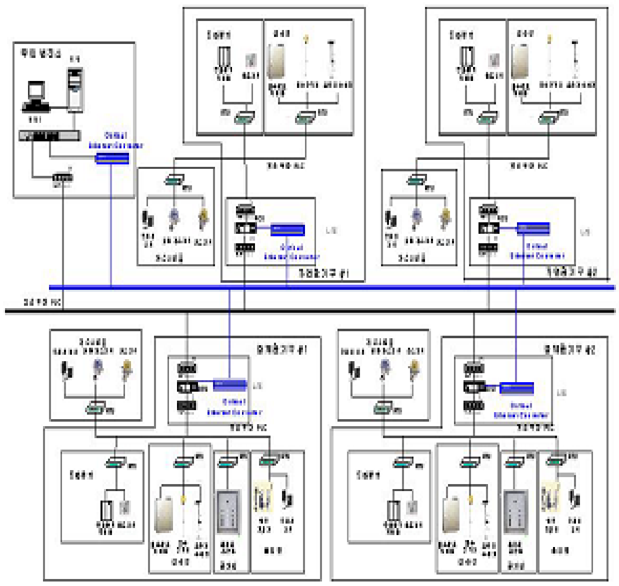

Fig. 3 The basic structure of monitoring and control system installed in Kang-Dong utility-pipe conduit in Seoul, Korea

The existing monitoring system needs additional communication lines to monitor and control devices. On the other hand, our system designed in this study needs no additional lines for communication because it uses power line for advanced skills like monitoring and control device, voice communication, and image-watching.

3.2 Long-distance PLC communication technology

In general, utility-pipe conduit extends hundreds of meters to tens of kilometers so that it is necessary to install PLC repeaters and signal bridges so as to connect each separate power section and organize a united PLC network if we apply PLC to control network in conduit. The designed PLC repeater is a module including amplifier, signal detector, and signal transmitter.

3.3 Remote Concentrator Unit (RCU)

RCU takes charge of monitoring / control data transmission between central control unit (CCU) and remote terminal and transmitting image and voice data. RCU communicates with CCU through high-speed PLC and with other RCUs by multi-drop method through high-speed PLC. In other side, RCU is connected to RTU and ultimately various sensors through low-speed PLC, and it gathers real-time data from sensors.

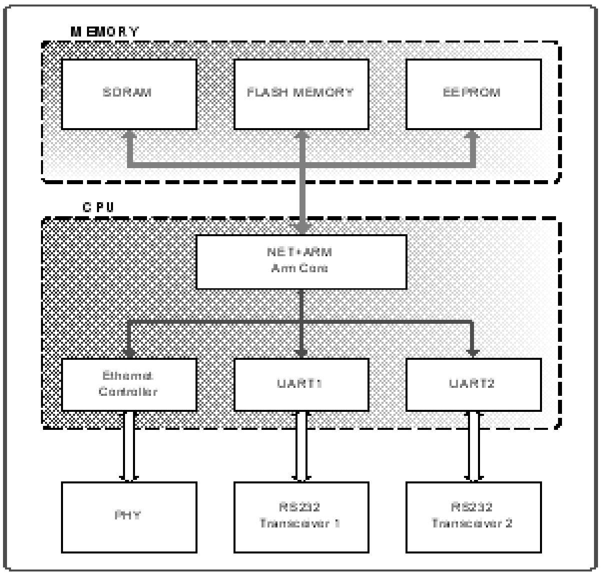

Fig. 4 Block diagram of RCU

3.4 Remote Terminal Unit (RTU)

RTU is located in the end point of PLC network and is in charge of interface with controlled devices. Remote terminal consists of low-speed PLC modem and input/output ports. It transmits the analog and digital signals to indicate controlled devices' states. It met high reliability and stability of equipment required maintaining the system's soundness. After installation, long-term test operation improved the durability of the system.

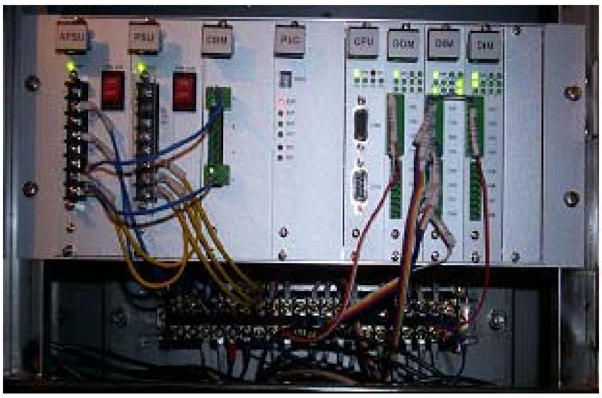
Fig. 5 RTU installed in Kang-Dong utility-pipe conduit

3.5 Sensor & input/output device with built-in PLC module

It is one of ultimate goals to reduce construction cost based upon control cable establishment and prevent analog and digital input/output work wrong. This can be achieved by applying PLC to the sensors and various controlled devices at the end of communication network and minimize the usage of the existing control cable. The main monitoring and control items are water-level monitor, ventilating fan monitor, lighting controller, noxious gas detector, and fire detection sensor.

3.6 PLC protocol for monitoring and control (DNP)

The protocols for monitoring and control basically support frame relay communication, and among them, we compare and analyze DNP v3.0, UCA v2.0, IEC 870-5-10 considering continuous version upgrade and standardization trend. As the result of analysis, it cannot be said that one of them is better or worse than others due to their own merits and demerits. However, although IEC is international standard and UCA has high technical potential, we chose to design the protocol that is compatible to DNP 3.0 because DNP is widely used based that it is optimized for SCADA (Supervisory Control and Data Acquisition) system. The designed protocol supports hierarchical and organic connection among network devices like sensors, input/output devices, long-distance PLC repeater, central control unit, and so on. This helps the system operate smoothly.

3.7 Design user interface (MMI)

In order to remove the inefficiency of the existing system, maximize the efficiency of monitoring conduit by using PLC modem, and reduce the cost of the system, it is designed on web-based Internet environment and to be familiar graphic interface by unifying the existing different program usage. It works on web browser environment, and is divided into three parts – database editor, monitoring and control program, and reporting program.

Fig. 6 DB Editor

3.7.1 Database editor

It is the program that adds, modifies, and deletes the properties and data of LS, RCU, RTU, analog sensors, digital sensors. The general user can only do inquiry, but on the other hand, administrator can modify and delete data.

3.7.2 Monitoring and control program

The old program indicated alarm and event on character-based popup windows. This new program indicates accurately the information of sensors, RTU, and RCU in concordance with distribution diagram.

3.7.3 Reporting program

This program lets us to confirm monthly or annually the data stored in database when there is variation of sensors or conduit. It also helps us utilize the statistical data strategically.

3.8 Voice communication and security system

The existing monitoring and control system in conduit used high-priced LCX cable for voice communication so that it is expensive and takes long times to install the communication line. Here, we develop efficient voice communication system to which directivity antenna and relay system is applied. It reduces installation expense and material cost, and the maintenance and repair of the system is easy hereafter. And we improve the security of facilities and convenience of management by installing security system like entrance monitoring and watch-camera.

4. CHARACTER OF PLC IN CONDUIT

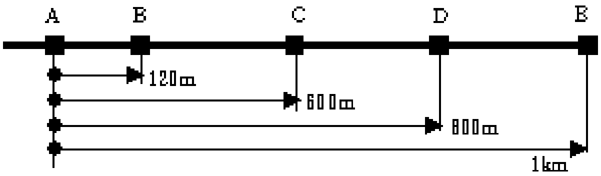

Fig. 7 Measurement points of PLC test

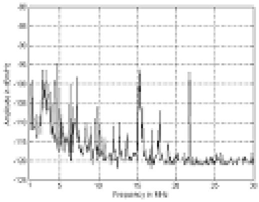

Fig. 8 Noise at A point

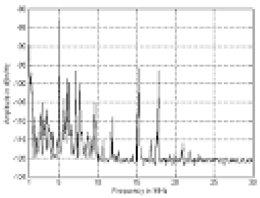

Fig. 9 Noise at B point

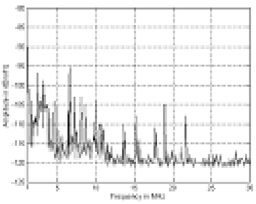

Fig. 10 Noise at C point

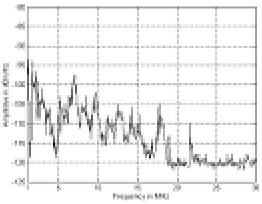

Fig. 11 Noise at D point

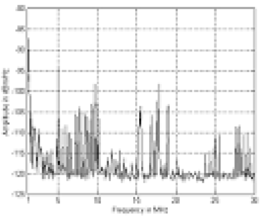

Fig. 12 Noise at E point

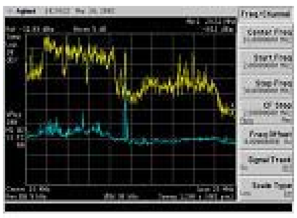

Fig. 13 PLC signal power

The field-test system in this study was installed in Kang-Dong conduit in Seoul, Korea. The conduit is 1.2km, and 154kV-transmission lines and 22.9kV-distribution lines are laid there. We performed power line communication test along the power line in the conduit and measured the related properties. The test point is 120m, 600m, 800m, and 1km far from the exit of the conduit and communication test and noise measurement test was done.

We used Agilent E7402A EMC Analyzer and high frequency power line signal coupler to measure noise in the conduit. Fig. 8 ~ 12 show measured noise spectrum density. Noise is generally below 80dB, which is good. Frequency and noise are seen to be in inverse proportion each other. The signal appeared regularly in 15MHz is seemed to be signal induced in power line by short-wave broadcasting or amateur radio signal.

In data communication test, we installed two notebooks connected to PLC modems at both ends of the test line. Then, one operated FTP server and the other worked FTP client. FTP server was fixed at ‘A’ point and FTP client moved to other points at each test (fig. 7). The used modem is valuation modem of Intellon that meets HomePlug standard requirements. As the results of the test, the communication was stable in 600m of distance, and PLC repeaters were used to extend the distance up to more than 600m. Fig. 13 indicated communication signal of PLC modem (upper line). The signal power in some points of signal frequency bandwidth shows ‘notch’ form. It is to avoid interference between PLC and the existing frequency bandwidth.

5. CONCLUSION

The existing monitoring and control systems in conduit use optical fiber and LCX so that it is very expensive and of poor lasting quality in poor conduit surroundings. It also needs high cost for maintenance and repair because of frequent breakdown.

In this study, we apply PLC to control communication in utility-pipe conduit. It reduces manpower and cost for monitoring and control of conduit, prevents damage to facilities by fire or water leakage in advance, and improves the soundness of conduit. Our research can be used as a basic data when any control system using PLC is developed in the future.

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