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Development of substation integrated protection and control system: design and practical application

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SUMMARY

The conventional protection, control and monitoring system of transmission and substation equipment consists primarily of analog devices which cannot adequately meet the new requirements. Moreover, analog devices are thought to be obstacles in the automation of control and monitoring processes. And this system was separated and isolated then the units were connected by hardwiring. We have developed a new integrated protection and control system using digital technology based on the concept of system integration.

This paper describes the IDPACS (Integrated Digital Protection and Control System), which adopts advanced computer technology, synthesizes software and hardware using microprocessors and uses optical communication techniques to produce high-speed and highly reliable substation protection and control equipment.

Keywords

System Integration , Protection, Automation, Digital Relay

1. INTRODUCTION

The increasing demand for electrical energy, the increasing complexity and size of the power industry, the overall improvement in lifestyle have come together to produce a need for the reliable and high quality transmission of electricity. Consequently, the importance of a substation protection and control system is increasing in the reliability of the power supply. On the other hand, changes in social thought and competition in the power industry have decreased the cost. These factors have lead to the increased requirement for automated and unmanned substations. Therefore, the information intensive application which gathers, processes, and shares devices information is required.

At KEPRI, due to the changes in the electrical industry, we must adapt the changes in the trends to automated and unmanned substations. Using microprocessor technology, optical fiber communication technology, and sensors we have developed a method to protect and control and monitor automated unmanned substations. In this paper we will introduce IDPACS : Integrated Digital Protection and Control System.

2. Environmental Changes in Power System

2.1 Social Environmental Changes

The development of industry has produced an increasing demand for convenient and clean electrical energy. Furthermore, with advances in technology being made daily, the use of microprocessor-based electrical equipment, including semi-conductor memory is also rapidly gaining use in increasing numbers of fields. So, the reliance on electrical energy in residential and industrial uses in terms of quantity and quality is increasing. As such, the effect of a power supply failure or disturbance in quality, even for short periods of time will have serious consequences.

On the other hand, in order to meet the increase in electrical demand, the configuration of power system equipment is being enlarged and growing more complex daily. If there were even a small fault within a system, the fault will propagate into a power system, therefore it is essential to protect and control such systems.

Additionally, the spreading phenomenon of avoiding multiple shifts and the aggravative burden on cost price resulting from the rising cost of labor, have resulted in a lack of trained experts in substation operation.

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Unmanned and automated operation of substations will therefore become mandatory in terms of the utility business. Furthermore, the majority of electrical power equipment which is located in numerous and diverse substations, require effective and diverse functional remote control and supervision.

As mentioned above, if we should briefly summarize the needs of integrated automation and control system of substation, we could say it is like Table -1.

Factors	Requirments
* Increased dependency on electricity in modern life * Enlarged and complicated power system - Need to reduce of power failure produced by faults - Need of prompt power recover - Extension effect of faults	*High reliability of protection and control system - accuracy - stability - rapidity
* Rising labour costs * Avoidance of shift work	* Automated and unmaned facilities
* Increased competitiveness in the power industry	* Independent protection and control technology * Localization of equip-ment production
* Lack of technical expertise	*Accumulation and application of expert knowledge using intelligent system

Table - 1. Requirements for a protection and control system

B. Realization of High Level Protection and Control by Advanced Technology

Substation protection and control systems have significant functions that are directly concerned with the operation and the protection of root networks. Some functions include the following. First, the rapid elimination and prevention of spreading faults which can occur in transmission lines, bus, power transformers. Second, the voltage regulation. Third, the simple circuit on/off control operations. Forth, the restoration power when faults do occur. And so on.

As such a system should maintain its performance in order to keep a high degree of reliability. In order to do this, it is absolutely essential that substation protection and control systems should be operated correctly, even if the power system equipment is changed or upgraded to re-inforce or improve its function.

However, at present there is not an existing protection and control system that can meet the requirements in substation protection, control, and supervision that are discussed above. For example, those of rapid and diverse fault detection, the enhancement of control and supervision, automation and rationalization in the checking and repair of equipment, multi-modal remote control and supervision and the creation of an intelligent system.

To complicate matters, existing substation facilities which execute the protection, control and monitoring of substation equipment have adopted fully analog devices or partially digitalized protective relay devices. It therefore becomes extremely difficult or nearly impossible to improve the performance of, or to diversify the functions of such facilities to satisfy all potential new needs.

In order to meet such increasing requirements, the extension of existing system configurations produces an increase in enormous numbers of control cables between local apparati such as CT, PT, sensors, and control and protection devices. Furthermore, the limitations of existing substation security may yield ever-increasing risks of substation shutdown resulting from problems in control circuits and difficulties arising from the consideration of suitable countermeasures to such situations. Additionally, problems such as longer periods of construction that will become necessary due to the placement, connection and checking of control cables, the complexity of system operations, maintenance, and circuit monitoring at the time that the substation is constructed, will all lead to an increase in substation construction costs.

Similarly, conventional analog devices are thought to be obstacles in the automation of control and monitoring, and in coordinating with remote central supervising systems such as EMS and SCADA. Therefore the adoption of digitalized protection and control equipment is a growing worldwide trend in the field of power system.

It should also be noted that computer technology and the synthesis of software and hardware have been making rapid progress in recent years as have highly reliable optical communication techniques.

By adopting these advanced technologies into substation protection and control equipment, a new type of system can be organized - namely where local digitalized protection and control devices are microprocessor based. Such a system offers a high information processing capacity, a substation main computer with a human interface, diversified data processing capabilities, and the opportunity for co-ordination with other automated systems. Notably, all control devices are interconnected in a local area network via optical fiber.

Improved functions of new protection and control systems based on advanced technologies are summarized below in table 2

Advanced technology item	Function improvement
*Memory and arithmetic device -Microprocessor -Artificial Neural Network	*Processing mass data *Execute multi-function *Flexibility *Self-diagnosis ability
*High-speed and mass information transmission device -Optical Fiber	*Noiseless mass data transmission
*High-sensitivity sensing device -various kind of Sensors	*Power equipment auto-diagnosis, *Status diagnosis ability

Table - 2. System functions improved by advanced technologies

3. Development Status of Substation Automation System

Until recently substation protection and control systems have consisted primarily of analog devices which only have single functions and are connected by hard wiring. However, newer systems consist of digitalized and integrated devices that are capable of executing multiple functions. This has been a crucial step in the realization of an automated, unmanned and intelligent substation.

As such, Integrated Digital Protection and Control System, called IDPACS, can be installed in substations or power generators to execute multiple functions which can include 1) protection due to a fault or an abnormal status, 2) self-supervision and diagnosis of operation status, 3) the control of all power equipment - transmission lines, power transformers, bus, distribution lines, reactors and capacitors, 4) providing all data gathered from peripheral systems to central systems such as SCADA, EMS, local operators and any relevant engineers, and 5) the linking with other automated systems such as those involved in an expert support operations, and equipment fault prediction.

In advanced nations research into digitalized relay devices began in about 1975. Recently due to the rapid progress of computer and information processing techniques not only have protection devices in power systems and apparati been digitalized but devices used in data processing, event and alarm processing and system status monitoring and control functions have become concentrated in one system by the use of network communication. Additionally, as substations are becoming interconnected via high ranking substations, complete networks are being created. For example, Westinghouse and General Electric in the United States; ABB in Sweden; Toshiba, Hitachi and Mitsubishi in Japan have all developed various kinds of digitalized protective devices. Consequently, by combining separated devices into one system, they produced and developed their own integrated protection and control equipment for power systems and applied them in substations or in power generation.

In Korea, in accordance with one of the future plans of KEPCO, a unique Korean power utility corporation, some digitalized protective devices have been partially used in transmission and distribution lines. However, for further expansion, all protective relays used in all power equipment will have to be digitalized. By 1999 IDPACS will be first utilized in two newly constructed 154kV substations. After KEPCO has tested and evaluated the system's reliability, performance and function there are plans to apply this system to all 354kV and some 154kV substations that are to be constructed.

4. IDPACS development in KEPRI

Development of a digital relay and integrated automation system was begun in 1985 by KEPCO. Since that time KEPRI has developed a digital relay for 22.9kV distribution lines and 154kV transmission lines. From 1989 to 1992, KEPRI had developed a prototype of ICPACS jointly with EESRC (Electrical Engineering and Science Research Center) and carried out field tests at a 345kV substation. In order to put it to practical use, KEPRI carryied out research and development on a working practical system, with the participation of internal related enterprises form 1993 to 1997. The system's configuration is represented in Figure 1.

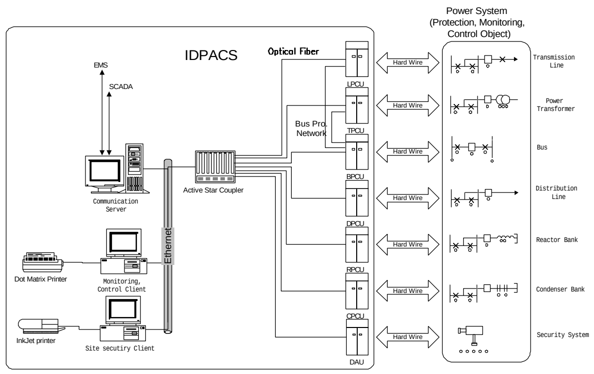

Fig - 1 The configuration of IDPACS

The brief description about the IDPACS is as follows.

4-1. System Configuration

Until recently protection and control devices have been installed solely in the control room. In IDPACS these are distributed in nearby field equipments and are linked via high-speed optical LAN with a central operation computer called SU(Station Unit).

4-2. System functions

Because the IDPACS functions depend upon software not hardware like conventional type, its functions and performances are decided by internal program. So the system’s capability is free-size within certain limitation. IDPACS, an effective automated and unmanned system, is divided into two units, and brief summary of each necessary functions are as follows.

Fundamental functions of protection and control units (PCU): Control and protect power equipment; acquisition of raw data

- controlling, monitoring and protecting devices from a fault; recording operating status
- preventing fault propagation
- transmitting and receiving information with the supervising system
- self-diagnosis and supervision
- fault recording and locating
- backup functions for system failures

Basic function of station unit (SU) : Control and monitor power equipment via field devices (PCU). Data access from PCU and process information. Organizing control and monitoring the optical network with PCU.

- control, diagnose, and monitor field equipment and record operation
- data acquisition and information supply to equipment fault prediction system
- data transfer function with the supervising system
- self-diagnosis and supervision
- control of site security and disaster protection system
- report generation to a local or remote operator
- data acquisition, storage and processing
- back-up system for system failures

4-3. Special feature of System

The IDPACS retains all the strong points of existing conventional systems in terms of reliability and maintenance and improves reliability by simplification of the system and by widely distributed processing. It further enhances functions, remote control performance and maintenance via the reinforcement of information links to other systems and between individual devices as well as by digitalizing information. In summary, IDPACS is a system that is well-mated for new environments. The characteristics and strengths of system include:

- software oriented; integrated system
- uniformity of hardware (facililty of extending existing functions by modifying software)
- high reliability through a distributed structure
- noise immunized data communication by using optical networks
- possibility of offering expert operating knowledge and intelligent functions
- high level remote supervision by supplying various types of data including visual information
- no requirement for a protection and control local house

4-3-1. Application of intelligent functions in protection and control

If any fault occurs in the transmission line or any other power devices, it should be detected and isolated from the system promptly. Due to variable operating parameters, different choice selection or numerous complicated calculations are required. For this reason an intelligent protection technique using a neural net or fuzzy logic application technology is included with conventional algorithms.

It is possible to avoid misoperation by an undisciplined operator during a fault or emergency state by applying an expert support system. In brief, in the case of an alarm or fault, IDPACS would provide a method of treatment and action for an operator or any related engineer, thereby allowing the operator to execute sequential controls by merely confirming messages.

4-3-2. Self Diagnosis

This function can be regarded as an auxiliary one. However, it must also be considered important from the viewpoint of reliability and in terms of a trend toward automation. One of the major benefits resulting from microprocessor technology is that the additional hardware is no longer necessary for self-diagnosis and supervision - a function that increases the availability and reliability by insuring the product and that system faults can be detected immediately. In the case of any internal system fault, all relevant data are transferred to local operators and remote engineers. This simplifies fault tracing and cuts repair time. The resulting reduction in down time increases reliability and security.

4-3-3. Fault Analysis & Trace Function

Rapid and efficient post-fault analysis is a crucial function to facilitate fault tracing and to avoid disruptions. The event data, including a change in status, internal system faults and all other information which can be of interest during an inner or outer fault condition at the substation is recorded sequentially and stored. Particularly in the case of a power failure, status changes in the IDPACS internal/external devices, as well as the voltage/current values in the power system are registered during a sufficient period of time both before and after the fault. And the stored data can be provided for fault analysis and trace functions to the central control room, to the substation operator workstations, and to the portable PCs.

4-3-4. Man-Machine Interface

As a medium for information transfer between operators and the system, GUI (Graphical User Interface) based, user-friendly and simplified operations are key requirements for the MMI. Additionally it must have an easy input/output function for processing information. Users can access integrated information on three levels: 1)local MMI display panels or portable PCs, 2) operator's PC, and 3) the remote engineer's PC.

The local MMI display panel or portable PC provides easy access and readability through exclusive serial ports. The operator's monitor which is connected to the control and monitoring network can display all the information relevant to the operation of the substation. The details and type of information can be selected by the operators. The remote engineer's monitor can present any information related to relay operations. All relay data and settings are accessible and can be changed by engineers and are sued for post-fault analysis and disturbance recording.

4-3-5. Modulization & Open Architecture System

Modulization of both software and hardware by unit function is necessary in order to obtain the clarity and reliability of each function and to facilitate the change of a system's configuration as individual components are modified, deleted or added as required.by variations within the system. Furthermore, it will be easy to either install or upgrade devices or software by designing an open architecture system that allows the integration of different types of devices from various manufacturers.

4-4. System Reliability

Increased system reliability can be provided by self-supervision and diagnosis:

- higher reliability and security
- lower maintenance costs
- simplified fault tracing
- increased availability

By using self-diagnosis, one of the major benefits of microprocessor technology, continuous and uninterrupted system hardware and software analysis is possible and will decrease system’s maintenance costs. CT and PT circuits, DC power supply, trip circuits and communication links are also monitored continuously, which further increases reliability. Self-supervision is the major benefit derived from IDPACS and it allows the entire system to be covered. Moreover, back-up functions can be included for even higher reliability.

4-5. Internal communication network

Optical LAN is structured to link information between each unit inside the system. The network is based on hierarchical substation apparati. In this type of system, there are two layers of communication networks. Substations are entirely controlled and supervised from the high station layer which are structured around the SU. Individual transmission lines, transformers, buses, etc., are controlled and protected via a lower field layer which are structured around bus protection and control unit.

4-6. Relations with other automated systems

IDPACS can be used in substation and power generation to operate whole power euipments.

It performs protection, control, and monitoring functions, including information gathering from field appratus. Also it can provide all accumulated data to upper remote control systems such as EMS,SCADA, and excute commands which are ordered by upper system, and communicate with automated distributed system,called ADS.

4-7. H/W Structure of Protection & Control Unit

The protection and control unit is a multi-processor structured hardware which adopts a VME(Versa Module Eurocard, IEC821, IEEE1024) bus as depicted in figure 2. By the function of processors, 16 bits, 32bits or DSP is used. The structure is shown in figure 2, and the function of each module is described below.

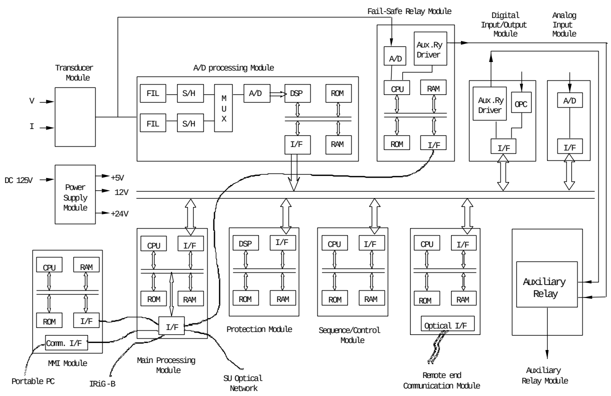

Fig 2.Block diagram of PCU H/W Modules

4-7-1. Analog Input Module

The module converts electrical input signals(V,I) from field apparatus into suitable values by using auxiliary CT and PT, and burden registors, etc.

4-7-2. A/D processing Module

This module is composed of an analog filter, sample and holder, multiplexer, A/D converter, DSP, ROM and RAM. It converts the analog input data from the transducer module into digital values, and accomplishes digital filtering via Fourier transformation using DSP.

This module produces the data which are required in protection calculations and measurements. It’s input ranges are designed to withstand 2.5 p.u. at voltage and 40 p.u. at current.

4-7-3. Fail-safe Relay Module

The function of this module is fault detection and is composed of FS (fail safe) hardware. The module set apart from main processing and protection algorithm modules. As this is composed of other protection factor TRIP output factors and an AND logic gate, it can produce a final trip output. The hardware is composed of an input A/D convertor, a protection logic and a digital output circuit.

4-7-4. Protection Algorithm Module

This module is composed of a 32-bit DSP, ROM and RAM. It performs all calculations of protection algorithm with data which are processed by the A/D module.

4-7-5. Main Processing Module

The module mainly consists of a 32-bit CPU, ROM, RAM and EEPROM. The functions of this module are setting relay operation value, system management, automated self-monitoring, local MMI interfaces such as local LCD panel or notebook and remote networking with SU(Station Unit) via optical fibers. The remote networking with SU uses IEEE 802.3(CSMA/CD).

4-7-6. Sequence & Control Module

This module is composed of a 32-bit CPU, ROM,RAM. It monitors digital input/output data, and processes programmable protection scheme logic downloaded from SU or Local MMI.

4-7-7. Remote end Communication Module(PCM current differential relay module)

This module consists of a 32-bit CPU, ROM, RAM, and optical network driver. It has two serial optical interface ports for PCM(Pulse Code Modulation) current differential relaying. These ports transmit and receive data at a speed of 1.544MBps with remote end relay via HDLC protocol. The network topology is a ring type.

4-7-8. Digital Input/Output Module

a) Input Module : Receives external signals from field apparatus such as CB,LS or other relays. It is isolated from external signals using a photo-coupler. The operation voltage is DC 125V.

b) Output Module : Delivers output to other relays or peripheral devices. It includes a circuit for the operation of contact point sign to drive other relays.

4-7-9. Auxiliary Relay Module

This module is composed of auxiliary relays to produce contact points for relay trip use, alarm use, in signaling and in communication carrier use. It provides the necessary NC (normally closed) contact to detect both internal failure and loss of auxiliary voltage.

4-7-10. Transducer Module

This module converts analog input values into digital data. It has a variable input range 0 ~ 1mA, 4 ~ 20mA, 0 ~ 5V, which are produced by sensors such as temperature sensors, pressure sensors, level sensors, tension sensors.

4-7-11. Power Source Module

The power source of PCU is the substation's DC battery. Its voltage rating is DC 125V, and normal operation range is 84% ~ 116% of rating. The module contains a DC/DC converter and is the source of power for devices within the unit

4-7-12. Man-machine interface Module

This module is mainly composed of a LCD, LED, alphanumeric keys and a communication port. The MMI module can be placed on the front cover or outside. The function of the MMI module is monitoring, setting and operation. It has a RS-232 serial port to connect to PCs.

6. Benifits of Substation Automation System

From the explanations above, the new type of integrated protection control unit which is an integration of digital hardware, software, and optical communication arrays using networking techniques, can satisfy the growing demands in the field of power system operation. The following results are expected when the new system is applied:

- increase in power system stability through high quality monitoring and control
- decrease in substation maintenance costs via unmanned operation and shortened periods of equipment diagnosis
- enhancement of EMS, SCADA functions
- enhancement of security and anti-disaster monitoring
- lower total construction costs due to reductions in on-site and building construction
- increases in the value of remaining systems as flexible structures will allow for longevity and the possibility of continuous upgrades
- simplified design and construction, lower construction
- costs and shortened construction terms by reducing the number of control cables.

7. CONCLUSION

The IDPACS, which consists of a concentrated optical communication system, sensors, and microprocessor based technology is a very useful system to help realize the goal of an automated and unmanned electrical power substation.

It is difficult for conventional protection and control systems to meet adequately and rapidly the increasing needs for changes in the environments of power substation operation.

Contrary to existing conventional systems, IDPACS is expandable, is geared towards multiple functions and is flexible in terms of its functions. In this system, active software lies at the core of the system and plays the major role.

In evaluating a new protection and control system, one should take into account the costs of all related equipments and activities. By observing this design principle, applying the integrated protection and control system will provide maximum value and give optimal results.

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