INTELLIGENT DISTRIBUTION EQUIPMENT FOR FAULT ANTICIPATION OF DISTRIBUTION NETWORK

Ju-yong Kim
KEPCO–South KOREA
juyong@kepco.co.kr

Jin-tae Cho
KEPCO– South KOREA
jintaecho@kepco.co.kr

Byung-sung Lee
KEPCO– South KOREA
95103928@kepco.co.kr

Il-keun Song
KEPCO–South KOREA
songilk@kepco.co.kr

ABSTRACT

Condition monitoring of distribution equipment is essential for the prediction of distribution system failures. So, KEPCO developed intelligent distribution equipments that can diagnose its degradation conditions through special sensors and monitor its performance by a distribution automation system. Intelligent circuit breakers, switchgears, reclosers, transformers and surge arresters have been developed. These communicate with the distribution automation system's control center via RTU by DNP3.0 protocol. KEPCO has also proposed diagnostic criterion for efficient maintenance. These pieces of intelligent equipment are installed in Jeju's smart-grid demonstration area. Underground cable is also important distribution equipment but was not considered for on-line monitoring; however, an intelligent underground cable monitoring system is under development. This distributed temperature monitoring system uses fiber optic cables for improved efficiency and cable life. Failure prediction and prompt restoration will be possible because of rapid detection and location of failure.

INTRODUCTION

As the requirements for power supply reliability have increased, new technologies have been incorporated into the operation of power distribution systems. In addition, an increasingly larger number of, and a greater variety of, switches are being used to help limit the impact of power failure incidents. Power lines, too, are becoming more complicated to reflect changes in the distribution system. Distribution equipment used in the field are now being required not only to have remote operation and simple data acquisition abilities of power line but also to ensure power quality information and self-diagnosis ability needed for planning and operation of distribution system. There has been an effort to build an intelligent distribution system that integrates SCADA (Supervisory Control and Data Acquisition) and DAS (Distribution Automation System); the development of two-way communication technology; and the invention of smart sensor technology to conduct remote monitoring of and reliability-evaluation on distribution equipment. High-performance devices that are capable of processing data fed from the smart sensors and data requested by the operator also must be developed.

In recent years, there have been a number of research findings on new concepts of power quality — interruptions, swells, sags, harmonics, surge, flicker, voltage unbalance — that can significantly affect precision control equipment and information and communication systems. To meet the demands, distribution equipment must adopt newer functions such as power quality measurement and analysis that will provide the distribution system operator with much-needed power quality information gathered from the field. In addition, it is necessary to develop distribution equipment that has built-in monitoring sensors including a PD (Partial Discharge) sensor, a temperature sensor, and a pressure sensor capable of diagnosing the conditions of field-installed distribution equipment more accurately and operating them accordingly.

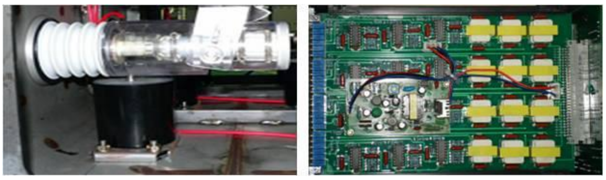
This study developed intelligent distribution equipments in which several sensors for detecting degradation conditions are installed in every distribution equipment, i.e., the switchgear, transformer, and arrester. In addition, a method for building and monitoring in real time an intelligent underground cable monitoring system is proposed in this paper.

INTELLIGENT SWITCHGEAR

Among the distribution equipment components, the circuit breaker and switchgear serve the most important role in blocking the failure-affected units and restoring the power network. Thus, a diagnostic sensor capable of minimizing the time required for correcting the failure and of monitoring the network status was selected and installed inside the intelligent switchgear. Using the sensor, this equipment was designed to diagnose its conditions, determine the power quality, and deliver system-operation information and transfer data to the main system. In addition, a CCU (Control and Communication Unit) that integrated the equipment-controller and the communication unit to ensure linkage to the main distribution automation system was also attached.

EVT

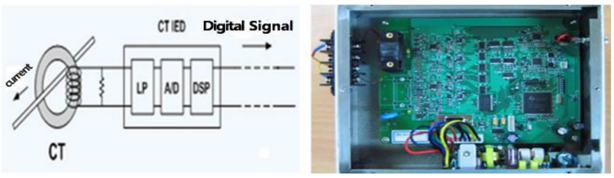
EVTs (Electronic Voltage Transformers) that are used in power distribution systems are divided roughly into two categories: resistive dividers, using resistance, and capacitive dividers, using a capacitor. The latter is the more commonly used type. The voltage sensor currently used in switches and circuit breakers of the distribution automation system is the capacitive voltage sensor, with a Grade 3.0 precision performance. However, its performance fluctuates with the environment, resulting in decreased measurement reliability. Thus, an EVT was developed with improving the performance accuracy using resistance to ensure higher stability against temperature changes in this study. The newly developed EVT shown in Fig. 1 was subjected to insulation testing, PD testing, and temperature testing, and its satisfactory performance was verified.



(a) (b)
Fig. 1. (a) The developed EVT and (b) it's driving circuit

ECT

ECTs (Electronic Current Transformers) shown in Fig.2 were developed to ensure both protection and measurement. The device compensates the secondary transformer current transmitted via analog input in the DSP (Digital Signal Processor) and then transmits the analog voltage signal to the intelligent distribution equipment.



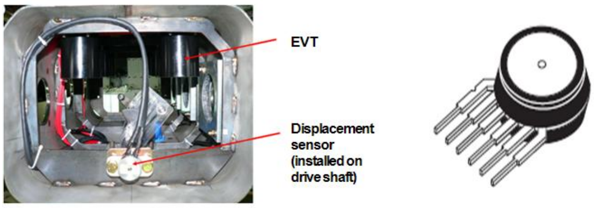
(a) (b)
Fig. 2. (a) Schematic of the developed ECT and (b) it's driving circuit

Displacement and velocity sensor

The purpose of measuring electrode displacement is to check on the circuit breaker of error-free operation status by monitoring the device's operating characteristics inside the intelligent distribution equipment and to prevent failures resulting from circuit breaker. The sensors are not supposed to affect the existing equipment, and are expected to guarantee long-term reliability. While selecting the locations in which the sensors were to be installed, priority was given to locations that are capable of maintaining insulation performance and directly reflecting circuit breaker operating status, and of allowing easy measurement of the rotation of the drive shaft, as shown in Fig. 3(a).

Gas pressure sensor

Both the gas pressure and temperature inside the switchgear as shown in Fig. 3(b) were measured simultaneously via semiconductor sensors with long service life and high stability. With this approach, calculating gas pressure that reflects the temperature condition inside the switch became possible. In other words, after measuring the gas pressure and temperature, the measured pressure was converted into the pressure that corresponds to the reference temperature (20 ℃) and was displayed for users. The converted pressure allowed users to determine the insulation and arc-extinguishing performance status of the device. The pressure that was measured via the sensor is an absolute pressure. The sensor was structured such that even a pressure of 0 kg/cm^2, which is under 1 atmospheric pressure, could be measured. The sensitivity of the sensor was 6.4 mV/kPa and, when converted into the kg/cm^2 unit, was approximately 628 mV per kg/cm^2



(a) (b)
Fig. 3. (a) Displacement sensor and (b) Gas pressure sensor

PD sensor

A PD(Partial Discharge) sensor is installed in the gas insulated equipment to monitor the discharge status continuously. An omni-directional, monopole-type UHF PD sensor has the appearance as shown in Fig. 4.

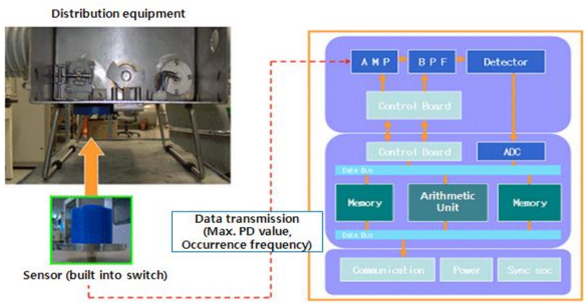
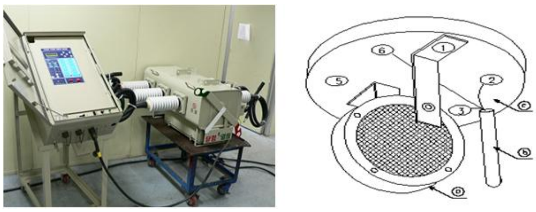


Fig. 4. Partial discharge sensor

A full-wave 3D EM simulator was used to carry out modeling on the gas insulated equipment for the sensor design. Afterward, the EM wave propagation mode and EM field characteristics operating inside the equipment were analyzed, and the sensor location and frequency band were selected. This was followed by determining the detailed specifications of the sensor, based on the selected frequency band. The band selection ensured that the same frequency was applied to the switches, re-closers, and circuit breakers.

The capacitor coupling method was used to measure the internal PD of the intelligent switchgear. The PD-measuring module was manufactured to form a single body unit that includes the control device. The design helped reduce the volume and economize the measuring operation.

The built-in sensors include 6 EVT sensors for measuring voltage; 3 ECT sensors for measuring current; a PD sensor; and a displacement sensor installed inside the switchgear. With all of these sensors installed inside the cabinet, the internal structure became rather complicated compared to existing models. Fig. 5(a) illustrates the prototype of the completed main body and CCU.



(a) (b)

Fig. 5. (a) Prototype of the intelligent switchgear and (b) porous sensor

INTELLIGENT TRANSFORMER

To diagnose the degradation of the oil immersed transformer, heat-degraded transformer oil, metallic particles, or sludge that is absorbed in a porous

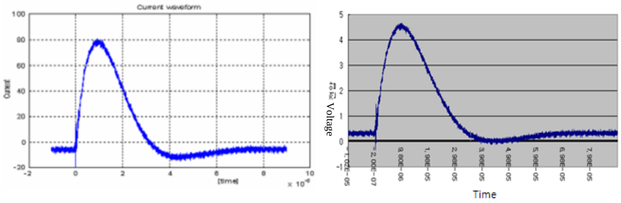
sensor (100 ~ 200μm) shown in Fig. 5(b) is subjected to a DC 2,000 V current. The result is the increased leakage current running between the poles. By measuring the difference in the leakage current, degradation condition of the transformer is predicted.

Short circuit status is determined by detecting the leakage current flowing through the secondary grounding cable of the pad-mounted transformer via CT (X_0), and by computing the leakage current (harmonic wave, unbalanced current, etc.) in the PQM (Power Quality Monitor). To prevent failures resulting from an overheating incident caused by a failure of the transformer's primary elbow connector, a temperature sensor was attached to the surface of the elbow connector, and fluctuations in the temperature were examined. This helped prevent heat damage to the transformer and subsequent system failures. Additionally, several types of sensors were installed — pressure sensor, moisture sensor, hydrogen sensor, and open/close detection sensor for the transformer. Also, the CT and PT were installed to measure power quality information of the transformer.

SURGE AND ARRESTER MONITORING

This study aimed at developing a device that is capable of remotely monitoring lightning incidents on a real-time basis and of monitoring the performance of the surge arrester that protects power equipment/systems against lightning-induced and switching surges. By developing this device, the study also sought to improve the reliability of distribution systems.

The developed product is comprised of a sensor unit and measurement unit. The sensor unit consists of a Rogowski coil sensor for measuring the surge propagating through the distribution network; and a precision CT for measuring arrester leakage current. The measurement unit analyzes the surge signal that was fed to the Rogowski coil sensor; and classifies the signal into different categories such as surge frequency, magnitude, and waveform. The unit also examines the arrester leakage current received via the precision CT; analyzes the current in terms of harmonics, resistance and capacity; and transmits the data to the main system. The graphs from Fig. 6 below summarize the results of input surge wave measurements.



(a) (b)

Fig. 6. (a) Input surge and (b) measurement result

INTELLIGENT COMPACT SUBSTATION

The prototype of CSS (Compact Substation) is a novel, intelligent distribution equipment with added features of condition monitoring, self-diagnosis, and real-time load control. The prototype is divided into a high-voltage transformer; a low-voltage distribution unit; and a CCU that monitors and controls the said transformer and distribution unit. An assortment of sensors was used to help realize seamless monitoring at the CCU. The types of sensors used for the CSS include Hall sensor; gas density sensor; ECT; EVT; thermocouple sensor; level sensor; and PD sensor. Hall sensors in particular transmit electric current signals of the trip/close coil in the circuit breaker motor mechanism to the CCU, and monitor the operating status of the motor.

Fig. 7. Compact substation

PERFORMANCE TEST

For this study, a test-bed at the KEPCO's Gochang Power Testing Center as shown in Fig. 8(a) was created in which testing of the intelligent distribution equipments was to be carried out. The newly created distribution network of test-bed made it possible to test the equipments under conditions that are nearly identical to those of the field test. By combining 4 pad-mounted switches, an overhead and underground distribution network was built to allow the demonstration testing to take place under a various conditions.

During the demonstration test, a communication performance test was carried out on the intelligent distribution equipments to verify the effectiveness of the system's communication protocol as well as the transmission performance of fault current waves and various events. Also, a load test was performed for each equipments to compare and evaluate their precision performance of load current and two-way current detection characteristics under actual load application conditions. Based on the comparison and evaluation, the minimum current-detection standard was determined, and directional detection algorithms and phase detection algorithms were strengthened. In addition, application programs were used for intelligent equipments to test the diagnostic, measurement, capacitor-testing, and data-transmitting abilities. Any functional flaws found were corrected, and a performance test was conducted by linking the equipments to the main unit of the distribution automation system.

INTELLIGENT CABLE MONITORING

Major functions that must be possessed by underground distribution cables include detection of overload temperature, impending cable failure and accurate fault location. Accurate fault detection and location can prevent reclosing of circuit breakers installed in a substation. This system can also detect high impedance ground faults but must calculate cables' real-time rating through conductor temperature estimation.

Fig. 8(b) shows a configuration diagram of the entire system.

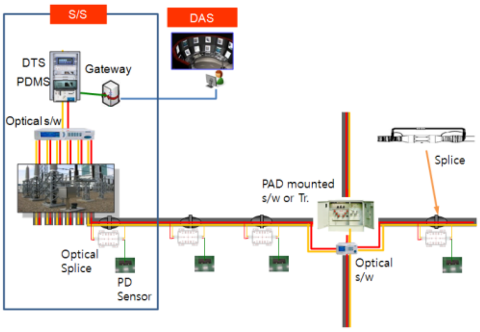


Fig. 8. Distribution DTS configuration

Intelligent DTS is installed at the distribution control center and operated with the distribution automation system. This optical fiber composite underground cable monitoring system consists of optical fiber cables for measuring temperature distributions; a server for the storage of measured data; a PC for driving the operation software; a gateway that can transmit data to the distribution automation system; a channel selection optical switch for determining laser injection cable; optical joint box and mobile partial discharge measurement device for the pre-molded splice; and route change optical switch used to select optical fiber cable for laser transmission from among several cables in the pad-mounted switch because the underground cable branches off several cables at the pad-mounted switchgears and transformers. As explained above, since underground distribution cables have many feeders and branch circuits, monitoring all circuits in real time simultaneously is inefficient and prohibitively expensive. Therefore, the system should be designed to monitor many feeders in succession with a minimum number of DTS channels.

CONCLUSION

In this study we developed several kinds intelligent distribution equipment. Performance assessment was carried out at the outdoor field test. And then all of these equipment except cable monitoring system are installed at Jeju island smart grid demonstration area in KOREA and operating now. On the other hand intelligent cable monitoring system was installed at outdoor test yard and it's performance will be assessed in this year.

In the future these intelligent distribution equipment will be install in the field and it can support self healing of distribution network with distribution automation system.

ACKNOWLEDGEMENTS

This research was made possible by the support of the Ministry of Knowledge Economy of the Republic of Korea.

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