MEDIUM VOLTAGE OPTICAL FIBER COMPOSITE POWER CABLE SYSTEM FOR SMART GRID

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ABSTRACT

Failure of power distribution network causes significant disaster due to its concentrated load and great complexity. In order to prevent failures of power distribution network, power distribution network equipment is getting intelligent to monitor and diagnose a power distribution network in real time. However deployment of intelligent equipments costs a lot, because supplementary communication network is required for communication between intelligent equipments. In order to reduce the cost occurred by additional communication network, the cable system which will be introduced in this paper enables power transmission and data communication without additional communication network by installing optical fiber composite power cable. Furthermore it helps efficient management of power distribution network as total integrated solution which monitors, diagnoses and controls the network.

INTRODUCTION

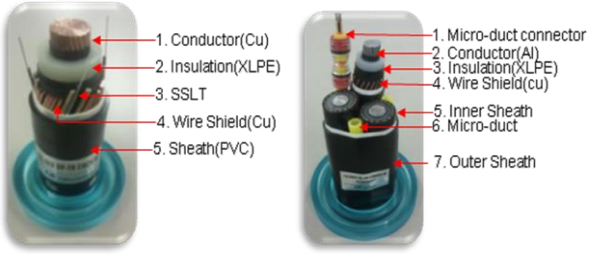
A power distribution network system has the purpose of maintaining a power distribution network at normal and optimal state. In order to attain the purpose above, it keeps monitoring and controlling the current state of the power distribution network, and predicts the condition in future as well.[1] To put it concretely, various components such as power cable, switchgear, circuit breaker are monitored and controlled remotely to prevent unexpected failure and loss. Based on the optical fiber composite power cable, our cable system monitors, controls, and diagnoses states of a power distribution network in real-time. Ultimately it is developed to contribute efficient, comprehensive management of power distribution network. The medium voltage optical fiber composite power cable system consists of following components:

- An optical fiber composite power cable which integrates optical fiber cable into power cable
- An optical joint box for an optical fiber composite power cable
- Distributed temperature measurement device through power cable laying route with optical fiber cable (DTS, Distributed Temperature Sensor)
- A module estimating conductor temperature from power cable temperature measured by DTS (CTM, Conductor Temperature Monitoring)
- A module yielding dynamic ampacity of power cable in real-time from estimated conductor temperature (DCR, Dynamic Current Rating)
- Communication system for monitoring and control of electrical equipment
- Communication status monitoring and diagnosis system
- PD(Partial Discharge) diagnosis system

BODY

OPTICAL FIBER COMPOSITE POWER CABLES AND JOINT

The optical-power composite cable reduces installation cost due to separate installation of communication network and power, and facilitates smart grid development by integrating optical fiber cable into power cable. It can be used at various scales of power distribution network such as urban area, plant, and building.

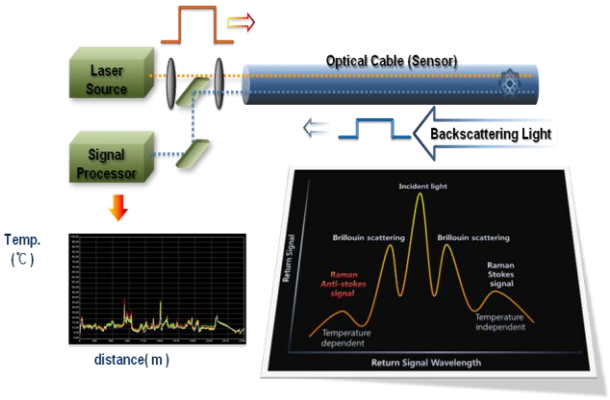


< Figure 1. SSLT type (left) and AB type (right) cable >

According to the structure of cable as shown in Figure 1, the optical fiber composite power cable has two types : SSLT(Stainless Steel Loose Tube) type and ABC(Air Blown Cable) type. ABC type cable affords to have three micro duct, which can install 144 core of optical cable by long distance air-blown installation method. Due to large number of optical fiber cables, ABC type cable is principally used for urban area where large-scale of communication networks and power grids are required. SSLT type cable is specialized for cable temperature monitoring because of its structure. It integrates SSLT including optical fibers between wire shields. SSLT is used to measure precise temperature of cable conductor, because of its high heat conductivity. Besides its structure is same to existing power cable so that SSLT type cable can use existing power cable accessories.

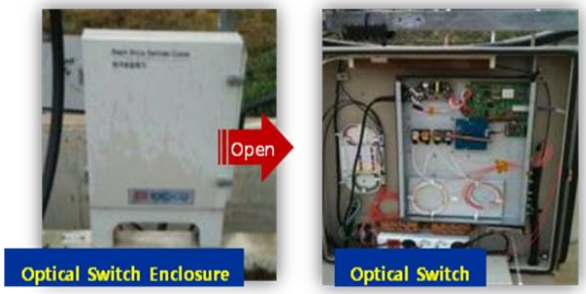
DISTRIBUTED TEMPERATUE SENSING

DTS(Distributed Temperature Sensing) measures distributed temperature of power cable along the laying route to identify fault location in advance with the optical fiber composite power cable. DTS measures distributed temperature by analyzing reflected optical signal of optical cable. As shown in Figure 2, reflected optical signal is divided into Raman scattering and rayleigh scattering according to its spectrum. DTS uses Raman scattering because of its sensitivity of ambient temperature. Raman scattering has two spectrum: anti-stokes spectrum and stokes spectrum. Anti-stokes spectrum is used for temperature measurement whereas stokes spectrum is used for distance and loss measurement.



< Figure 2. The priciple of DTS measurement >

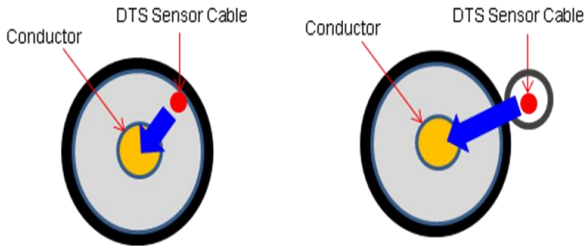
In power distribution network, power distribution line is branched off in 2 ~ 4 lines at switchgear. Thus in order to monitor of every branches of power distribution line, optical switch is developed to switch branches of optical lines. The optical switch alters optical line branches in order automatically in automatic mode, while it can be controlled remotely by operators in manual mode. Eventually the newly developed optical switch, as shown in Figure3, makes an operator can monitor distributed temperature of entire power distribution network. Besides it minimizes the loss of optical signal about 0.3 dB and improves its measurement distance to monitor entire power distribution network.



< Figure 3. Optical switch for temperature monitoring >

CONDUCTOR TEMPERATUE MONITORING

CTM(Conductor Temperature Monitoring) estimates temperature variation of conductor by analyzing dynamic heat transfer model. In order to calculate conductor temperature in real-time, CTM considers temperature thermal time constant based on IEC 60287 standard [3] and temperature measured by DTS according to ambient environment.

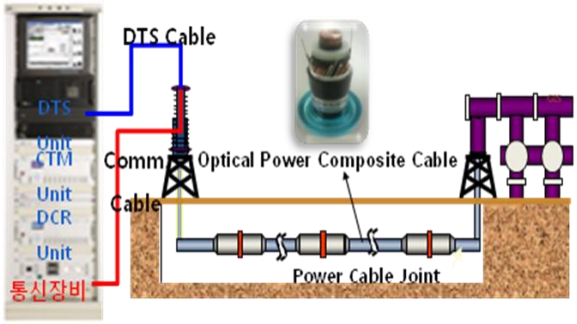


< Figure 4. SSLT type and AB type of CTM >

As shown in figure 4, SSLT type cable install its DTS sensor cable in different place with ABC type cable. Thus estimate method of conductor temperature is supposed to be different according to the type of optical-power composite cable.

DYNAMIC CURRENT RATING

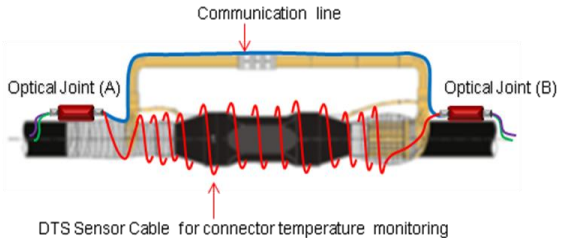
DCR(Dynamic Current Rating) evaluates ampacity of cable in real time by considering ambient environment. In order to evaluate the ampacity of cable in real-time, DCR uses the transient responses of load current. Thus it can yield the optimum level of overload operation in case of temporary load concentration. Eventually DCR improves stability and efficiency of power distribution network operation. DRS(Dynamic Rating System) consists of DTS, CTM and DCR units as shown in figure 5. This system yields the optimal ampacity of cable in real time to deal with probable emergency in operation. Besides it enables early fault detection and heat management, and is used to choose alternative route as well.



< Figure 5. Configurations of DRS >

OPTICAL JOINT BOX

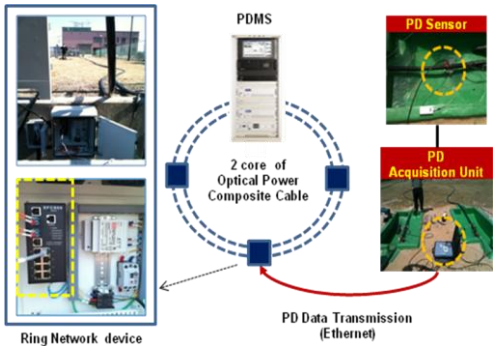
Each time an optical fiber composite power cable is connected to another one, an optical fiber cable has to be separated from the power cable and connected to another optical cable using optical joint box. However in order to connect optical cable with existing optical joint box, power cable is wasted due to structure of an optical joint box. In order to resolve the problem above, an optical joint box for optical fiber composite power cable is developed. As shown in figure 6, newly developed ones are installed at both end of a straight cable connector. Optical cables separated from the power cable are connected to the optical joint(A). An optical cable for DTS rolls the straight cable connector up to the optical joint(B), while one for communication is disposed on the neutral conductor. The newly developed optical joint box has been installed in practice. As a result, it is verified that the newly developed optical joint is effective to reduce waste of power cable without a significant modification of construction method. Besides short-circuit test and watertight test have been carried out to verify reliability.[2]



< Figure 6. Configurations of cable joint >

PARTIAL DISCHAGE MEASUREMENT SYSTEM

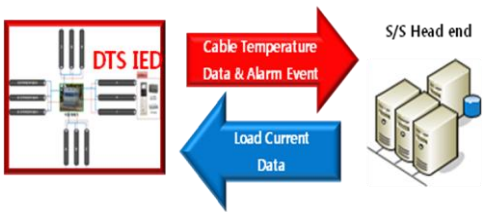
PDMS(Partial Discharge Monitoring System) diagnoses the insulation quality of power cable by analyzing PD(Partial Discharge) signal generated from power cable in real-time to prevent unexpected faults. Usually power cable connectors are required to be monitored with PDMS most carefully because they are vulnerable to PD. Considering type of PDMS for power cable connectors, portable type is more suitable than fixed type, because of environment condition and economic feasibility. PDMS consists of PD sensor, PD S/W. As shown in Figure 7, PD sensor transmits the optical signal converted from 3~50 MHz PD signal, through an optical communication line. PDMS selects the spectrum which has highest signal to noise ratio, to eliminate of pulse noise such as corona discharge or triggering noise. With these results PD analysis S/W analyzes and records the PD pattern in real-time.



< Figure 7. Configurations of PDMS >

IEC61850 COMMUNICATION

One of important concepts of smart grid is two way communication between electrical equipments in a power grid. In order to conceive two way communication in a power distribution network, it is expected that IEC 61850 standard is applied to IED(Intelligent Electrical Device)s in a power distribution network. Accordingly, the optical fiber composite power cable system is developed to support IEC 61850 standard.[4] The optical-power composite cable system exchanges specific section information with upper system according to IEC 61850 as shown in figure 8. It reports cable temperature data and event alarm to upper system while it receives load current data from upper system.



< Figure 8. IEC61850 communication >

All the data exchanged is defined in ICD(IED Capability Description) in accordance with IEC 61850. Table 1 represents example of data defined in ICD.

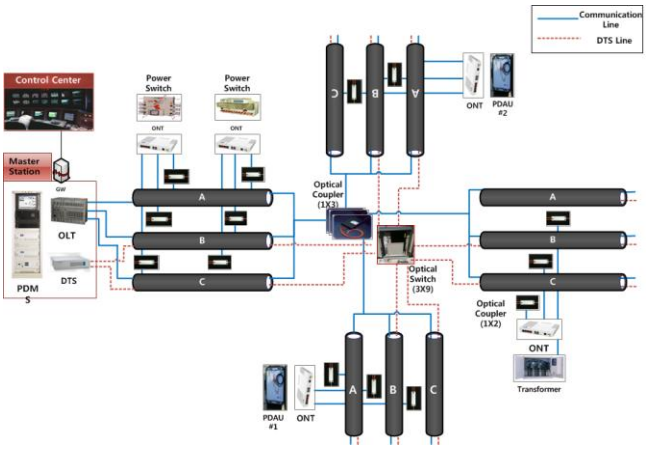
name	Data type
Measurement Data	Sections Configuration Data Sections Temperature Data
Fiber Break Alarm	Sections Fiber Break Alarm
Switch Fault Alarm	Optical Switch Alarm

DTS Fault Alarm	DTS System Fault Alarm

< Table 1. Data Definition in ICD >

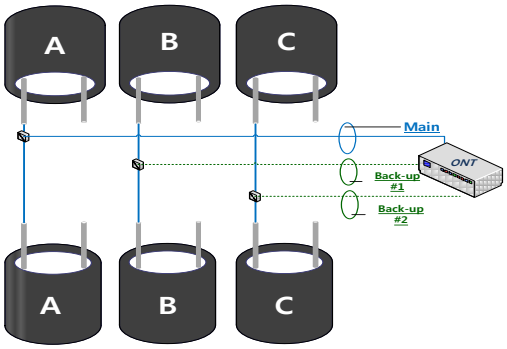
NETWORK CONFIGURATION

The optical fiber composite power cable provides stability of communication network with its dual ring network topology between electrical equipments.



< Figure 9. Network Configuration >

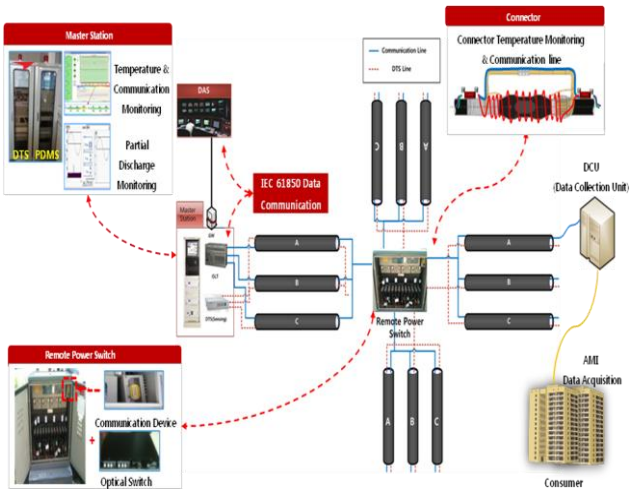
As shown in figure 9, the optical fiber composite power cable can provide FTTx (Fiber to The X) service with GPON(Gigabit Passive Optical Network) as well. Based on ITU-T G.984 standard, GPON enables one-many topology. Ultimately, with GPON service, the optical fiber composite power cable provides additional communication network for TPS(Tripple Play Service : Internet, VOIP, IPTV) as well. Besides, as shown in figure 10, it provides network redundancy to improve the reliability of communication network.



< Figure 10. Network Redundancy >

MEDIUM VOLTAGE CABLE SYSTEM FOR SMART GRID

In future, according to the increase of the number of nodes in power grid, it is expected that the amount of operating data and complexity of operation in power grid is increased rapidly. Thus future power grid is required to integrate communication network to provide reliability and efficiency. In order to provide reliability and efficiency in power distribution network, our medium voltage optical fiber composite power cable system integrates an optical-power composite cable, connectors, communication system, and monitoring system. An optical fiber composite power cable integrates optical fiber cable with power cable so that it can be used for cable monitoring unit and communication channel, which provides means to exchange the data. Based on the installation of an optical fiber composite power cable, this system prevents faults in advance with its monitoring systems such as PDMS, DRS. Besides it improves efficiency by reducing installation cost. Optical fiber composite power cable system provides the optimal solution for a power distribution network for smart grid.



CONCLUSION

In smart grid environment, power grid is required to integrate communication, monitoring and power transmission function into an integrated system. The medium voltage optical fiber composite power cable system is the integrated system for power distribution network, providing the efficient power grid which has economic feasibility and reliability. It has been applied in the experimental environment of KEPCO(Korea Electric Power Corporation) at Gochang, Korea. Its great performance is verified for 2 years through various tests including a long-term reliability test. In the near future, the solution will be applied to demonstration of KEPCO to operate in practice.

REFERENCES

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[3] IEC60287, "Electric cables – calculation of the current rating"

[4] IEC61850, "Communication networks and