A NEW SURGE PROTECTION SYSTEM AND A NEW METHOD OF SURGE DETECTION USING FIBER OPTICS

M. Inagaki[*], T. Miyajima[**], T. Ohira[**], Y. Sato[**], T. Sako[***], T. Kameoka[***]

*)The Chubu Electric Power Co., Inc. 20-1, Kitasekiyama, Odaka-cho,
Midori-ku, Nagoya 459 Japan
**)OKI Electric Industry Co., Ltd. 4-10-12, Shibaura, Minato-ku,
Tokyo 108 Japan
***)The Fujikura Cable Works, Ltd. 5-1, Kiba 1-chome, Koto-ku,
Tokyo 135 Japan

ABSTRACT

A new, economical protection system using fiber optics has been developed to protect existing local metallic cable systems from lightning.

A field trial system was installed at a hilltop microwave relay station which is often struck by lightning. The characteristics of the system and its fiber optics were investigated using a specially developed surge detection method employing fiber optics. A direct lightning strike demonstrated that the whole system functions very successfully and provided valuable data on surges.

Replacing the whole length of metallic cable with fiber cable would eliminate surge problems completely, but would be prohibitively expensive. We believe that a hybrid system presents the most economical solution. Using the system described to protect from direct surges requires the replacement of only the first few hundred meters of metallic cable. The rest of the system can be protected from induced surges by conventional means. Thus by applying this system to existing telecontrol or telecommunication cables, their reliability can be greatly increased at relatively little cost.

Further, the new method of surge detection developed in relation to this system shows many advantages over previous methods, and has the potential for wide application.

INTRODUCTION

Conventional telecommunication or telecontrol metallic cable networks suffer seriously from lightning surges. Usually lightning-induced surges in the cables are the major problem and a direct strike of lightning is rare. The former can be handled almost perfectly by conventional arresters and other protection circuits, but equipment on a hill top like microwave relay stations, are more likely to be hit directly. The large surges of current these direct strikes produce cause problems which are difficult to prevent. Microwave relay stations conventionally require metallic cables for remote supervision and telecontrol and for some telecommunication channels. These are not the main communication channels, but are important for network reliability and maintenance. Such stations are also supplied with electricity via metallic cables.

In these circumstances, when lightning strikes the lightning rod of the station, it induces a large back flashover current to the far end of the metallic cable. The more usual lightning-induced surges in the cable will also be conducted into the station at the same time. Although the latter sometimes affect the main microwave systems or power equipment, the former is the major surge problem. The station's electric power supply lines will also be vulnerable to the lightning surges, but they rely on different protection techniques (1), and as a last resort they can be cut off physically, and a generator switched in, when thunder approaches. The prediction of thunder plays an important role in this respect, but is not discussed here.

Fiber optics are well known to offer a protective system from surges because the optical fiber is not sensitive to electromagnetic disturbances. Replacing the whole metallic communication or telecontrol cable by a fiber cable would provide a perfect solution, but there are already so many metallic cable systems to microwave stations, most of them with small transmission capacity and are so long that this is economically unfeasible. To rescue all these existing systems economically using optical fiber cable, a new hybrid system was developed in which only a small portion of the existing metallic cable is replaced by a fiber cable, and the remaining existing metallic cable span is used effectively as before. Further, the existing terminal equipment at both ends is not changed.

Mt. Mikuni, height 701m, was selected for the field trial site. It is located north of the city of Nagoya, Aichi Prefecture, Japan, an area famous for thunderstorms. A microwave relay station on the mountain perform an important telecommunications role in the Nagoya area electric power supply network.

The field test system was installed in Sept. '77, consisting of electric to optical and vice-versa converter equipment and 300 meters of optical fiber cable. Several lightning surge detection systems were used.

One of them, a newly developed fiber optic system performed remarkably well and many other applications for it can be expected, e.g. in protection systems that use lightning prediction.

TRIAL SYSTEM

Figure 1 shows the system configuration. Formerly two pairs of conventional metallic wires in a cable ran the 13km between Seto City and Mt. Mikuni's station. One pair was for voice band data for supervision and telecontrol of the station, accommodating two, two-way channels of 200B FSK (Frequency Shift Keying) signals which we call CTC (Control Tone Channel). The other pair was used for one SSB AM signal cable carrier telephone channel each way. Only the first 300m of the existing cable route was replaced by a fiber cable. Optical terminals were installed at both ends of the optical fiber cable, one was mounted with power equipment on a pole and the other was installed in the station. The existing terminal equipment at each end and the remaining metallic cable span were used as before without any change.

Figure 2 shows the block diagram of the system and its surge detection facilities. Metallic pairs from the city terminal were connected to the optical terminal on the pole and were equipped with gap arresters and isolating transformers to protect from lightning-induced surges in the cable. The signals are combined in each direction, frequency modulated and converted to intensity modulated optical signals. Two fibers are necessary for this system, and the other two fibers in the cable were used for a trial PCM digital transmission. The power equipment on the pole also has an arrester and an isolating transformer at the interface with the commercial AC line input. Batteries in case of AC supply stoppages, a converter and a regulater were built into a house, the same size as the optical terminal house. To minimize heat rise in the pole equipment, the houses are of double wall construction, with natural ventilation between the walls. SV in Figure 2 is a supervisory function of the system. Failure of the pole equipment must be detected at the station, so stoppages of the optical power and the AC supply received at the pole cause alarms to be sent to the station using a pilot signal, where they are recorded on a printer. Base band channel allocation is shown in Figure 3 and the other major specifications of the system are listed in Table 1.

Fiber Cable Length

The separation length with fiber cable is one of the important parameters of this system, and it depends on the magnitude and longitudinal distribution of the earth potential which arises when lightning strikes. For example, a 100KA lightning surge current at 10Ω earth resistance (of transient impedance) generates 1000kV. The earth potential of the surrounding area also rises by an amount which decays exponentially with distance.

Decade decay per 20m has been reported (2), and 100m is enough to avoid the surge peak. 150m was decided on, which needed 300m of optical cable.

Modulation Method

FM-IM modulation was used. Direct optical intensity modulation was considered for simplicity, but environmental conditions around the pole equipment are so severe that level variation and optical linearity compensation are complexs, and power consumption can not be decreased. PCM encoding was also considered because of its good matching to optical devices, but its power consumption is much higher than other methods. The power consumption must be within the capacity of batteries.

Surge Detection System

It was necessary to provide certain surge detection facilities to evaluate the developed system's effectiveness, and four separate methods were employed.

The first method used gunpowder units to detect direct strikes of lightning to the lightning rod on the antenna tower of the microwave station. The large surge current explodes the gunpowder charge. They had already been installed.

The second was the thunder alarm system, which consisted of an atmospherics detector which was also already installed outside the station for another group's studies. The alarm signals from this detector were transmitted optically with a 30m fiber cord to the main station where they were recorded.

The third method was a conventional surge counter using a current detection coil connected across the power line input of the power equipment on the pole.

The last one was a surge detection system for lightning-induced surges on the communication metallic cable span. This method, using fiber optics, was specially developed by us, and is described in more detail in a later section.

Fiber and Fiber Cable

The fiber was “SILFA”, made by Fujikura Cable Works. The cable installed has four fibers in it and its tension member is made from FRP (Fiber-glass Reinforced Plastic). There are no metallic materials in the cable. Its characteristics are listed in Table 1.

This type of polymer-clad fiber is economical. Its large core diameter is suited to LED source coupling and its bandwidth is wide enough for short distance transmitting applications. The single fiber cord used for the surge detection system is the same type as the fiber of the cable.

This cable was installed in the same way and as easily as conventional metallic cable. The main fiber was spliced to the tail fibers of the optical source and detector devices with V-grooved splicers.

Optical Source and Detector Devices

The optical source was a GaAlAs double hetero structure Burrus-type LED, and the optical detector was a Si-PIN photodiode, both made by OKI Electric Industry. The driving current of the LED in this system was a few mA because of the short distance transmission, although it can be driven at over 50mA. Both devices are mounted in BNC connecters to which the tail fibers are attached, and they can be connected to the electric circuits of BNC receptacles.

Power Equipment

The power equipment on the pole must be protected from surges. Perfect isolation can be achieved with a solar battery system, which will be used in future. For reasons of economy, this system was supplied from a commercial AC line and protected with an isolating transformer and a conventional arrester circuit. These methods, also used on the metallic transmission lines, are only effective against lightning-induced surges and not against direct strikes. It is reasonable to suppose that direct strikes to the pole equipment are rare. The floating batteries can cope with a continuous AC power stoppages of up to 12 hours.

Additional System (Digital Transmission)

To check the accuracy of digital transmissions over this system in case of a direct strike of lightning, a 1.5 Mb/s random PCM signal was looped backed on a fiber as shown in Figure 2. Digital errors were recorded on a printer. Refer to the Results section for details.

NEW SURGE DETECTION METHOD

A new surge detection method using fiber optics was developed. The conventional method is known as a surge counter, and uses an induction coil to detect surge currents, which are counted in electrical circuits. It needs a power supply, and if the detected signals are to be transmitted to the far end, a special transmitter also. All this equipment must be perfectly protected from surges.

The developed method is the simplest one for detection and transmission to the far end, and perfectly free from surges. Figure 4 shows the method. One end of a fiber, the same type of fiber used in optical signal transmission, is attached to the glass wall of an arrester connected across the metallic line. The radiation from the arrester when activated by surges is transmitted directly to the far end of the fiber, and detectable at over 1 km.

Figure 5 shows the laboratory data. The light signal was detected with a PIN photo diode at 100m. The gap between the fiber end and the wall of the arrester was about 0.5mm and no lenses or optical collectors were used. Optimum fiber attachment angle is about 30° for a tri-electrode arrester as shown in Figure 5. The optical spectrum of the radiation from the arrester and the transmission fiber should be known exactly to facilitate exact estimation of transmission characteristics. The former is rather difficult to observe. In practice however, the magnitude of the electrical surges activating the arrester can be estimated from the detected peak current on the basis of experimental curves. The detected electric waveform is very similar to the surge current activated over the range investigated, but more experimental work remains to be done.

This method was used to observe the surges induced in the metallic cable lines at the pole, using a 250m fiber cord with a O/E converter and a comparator in the station, as shown in Figures 2 and 4.

RESULTS

Although this field trial will continue until March ’79, various data have already been obtained. Figure 6 shows the received optical power variations over 24 hours, observed at the pole equipment’s optical power monitor. It shows the direct dependency of the received optical power on the ambient temperature. Figure 6 and other observations lead to the conclusion that the variation of the received optical power with temperature is mainly due to the temperature-dependent change in the refractive index of the silicone fiber cladding.

Continuous recording of received optical power did not detected any alarm. Maximum and minimum temperatures at the pole equipment were 41°C and -10°C respectively between Dec ’77 and July ’78. AC power stoppages to the pole equipment were monitored continuously. 10 power cuts were detected between Oct ’77 and July ’78, the longest was about 200 minutes. The frequency and duration of stoppages increased in the thunder season. These data will be fed back to battery capacity design in the future.

Continuous recording of PCM transmission errors indicated some errors during periods when other electrical equipment was being installed and tested in the station, but ordinarily the estimated error rate was less than 10^{-13} at a received optical power of -30dBm. Even during a direct strike of lightning at the station, there were no errors.

The last data concerns lightning surges. Fortunately there was a direct strike of lightning to the station. The situation before and after the strike is illustrated in Figure 7. At 16:13 on 8th July ’78 the thunder alarm system detected thunder, indicating lightning about 10km away. Surges in the metallic cable were detected at the pole equipment’s arrester 8 times from 18:13 to 18:23. The largest surge at 18:20 was estimated to be at least 6000V, the highest level (level 4) of the comparater. At 20:03, the thunder alarm switched off. It was observed from the Seto City Station that other equipment in the Mikuni Station had failed during the storm. Examination of the gunpowder units attached to the antenna tower the next day indicated a direct lightning strike. The magnitude of the direct surge was estimated to be at least 7800A. The developed system functioned normally throughout the storm, and gave perfect protection to the network.

CONCLUSION

Despite many studies into the problems of current surges for direct lightning strikes in metallic cable communication systems, the described method of employing fiber optic cable in the vicinity of tall structures seems to offer the most practical and economic solution.

Further, the described system has the advantage that whereas most fiber optic transmission systems are developed for specific, new applications, it is ideally suited to the modification of existing, conventional networks.

The field trial demonstrated the effectiveness of the system in preventing disruptions due to direct lightning strikes, and points to the great improvement in reliability and maintenability that is possible for existing local networks.

It has been shown that the properties of optical fibers, fiber cables, and optical sources and detectors permit their practical application in mountainous areas.

The polymer clad fiber, which is rather economical, has a wide enough bandwidth over short distances to make the system suitable for application in other areas, such as in power transformer substation facilities, local telemetry systems and TV satellite systems.

Related to the field trial, a new method of surge detection was developed, also using fiber optics. This is superior to conventional methods in every way and gave excellent results. No active elements or power supply are needed for sensing the surge, and faithful transmission of the sensed signal is possible over 1km with perfect electrical isolation. It is suitable for use in many studies of lightning surges, and also has applications in higher systems for rapidly detecting trouble or data error due to any kind of surge, and where prediction of lightning surges plays a main role in system protection.

ACKNOWLEDGEMENTS

The authors would like to thank M. Muramatsu for carring out measurements and evaluations in the Central Technical Research Laboratory, Chubu Electric Power Co., Inc. and also Y. Shirochi and his colleagues who designed the equipment in the Communication System Research Laboratory, OKI Electric Industry Co., Ltd.

REFERENCES

1. G. OHWA, K. MATSUMOTO, Technical Report of Central Research Institute of Electric Power Industry (CRIEPI), JAPAN, No-177011, June ’77.

2. J. TOYAMA et al. “The basic design principles of surge protection for power generating stations and substations” CRIEPI. No-64019, Sept. 1964.

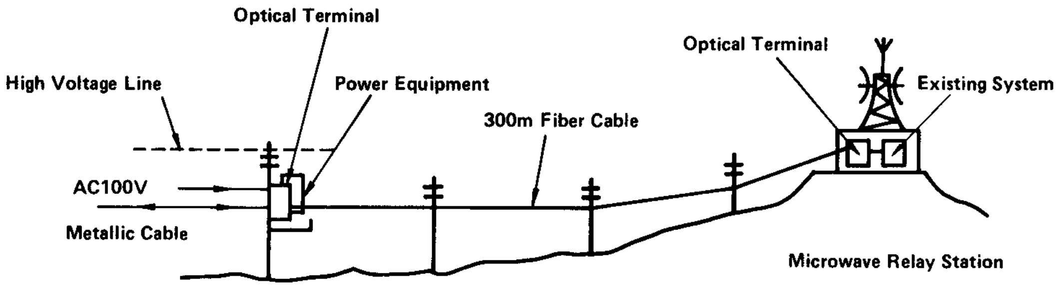

Figure 1 Trial System Configuration

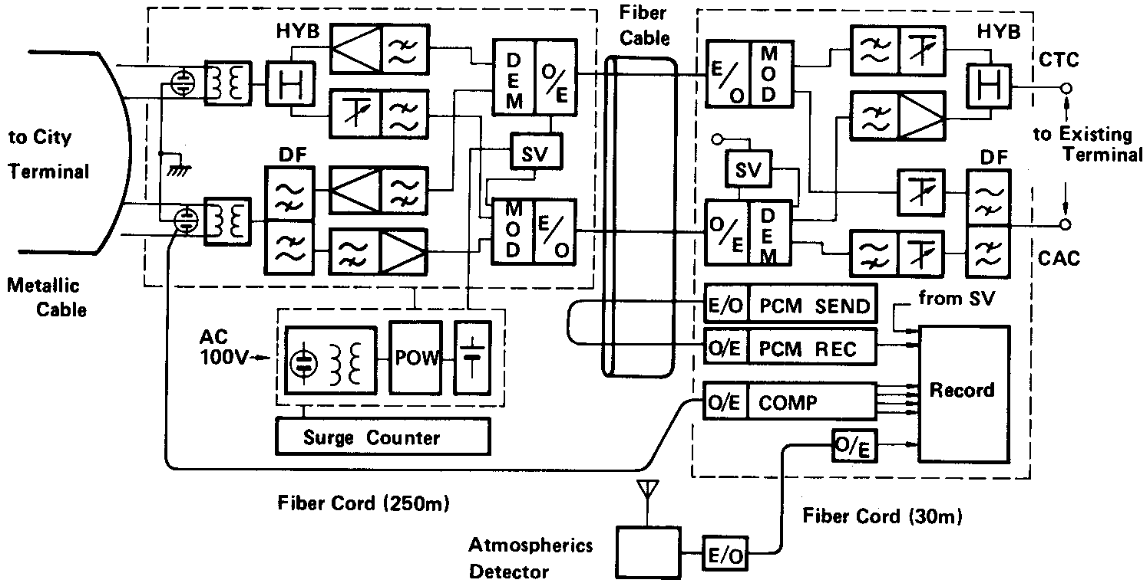

Figure 2 System Block Diagram

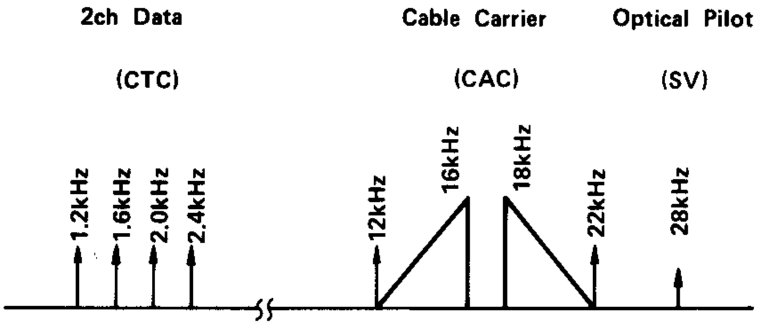

Figure 3 Base Band Channel Allocation

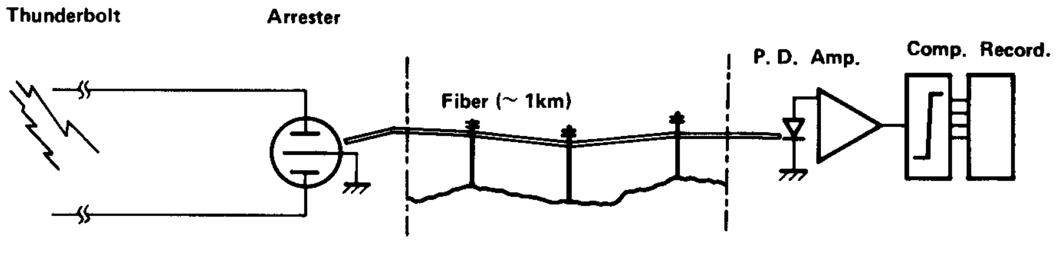

Figure 4 A New Surge Detection Method

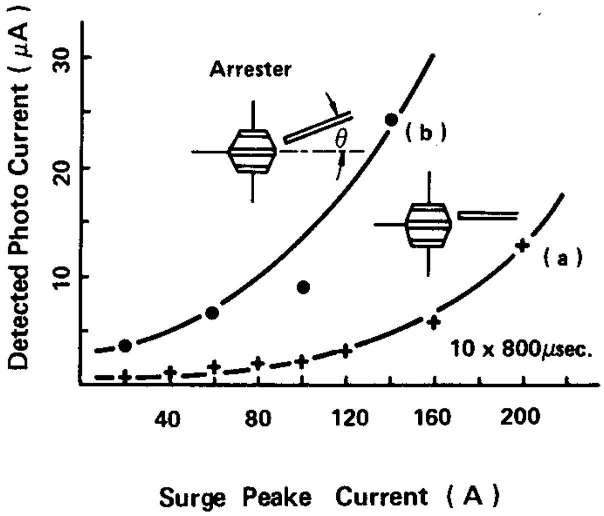

Figure 5 Photo Current Detected at 100m Fiber End

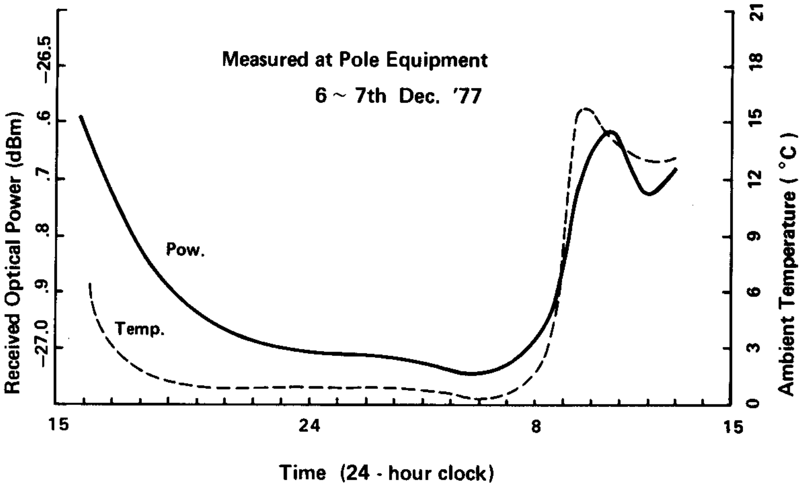

Figure 6 Received Optical Power Variation

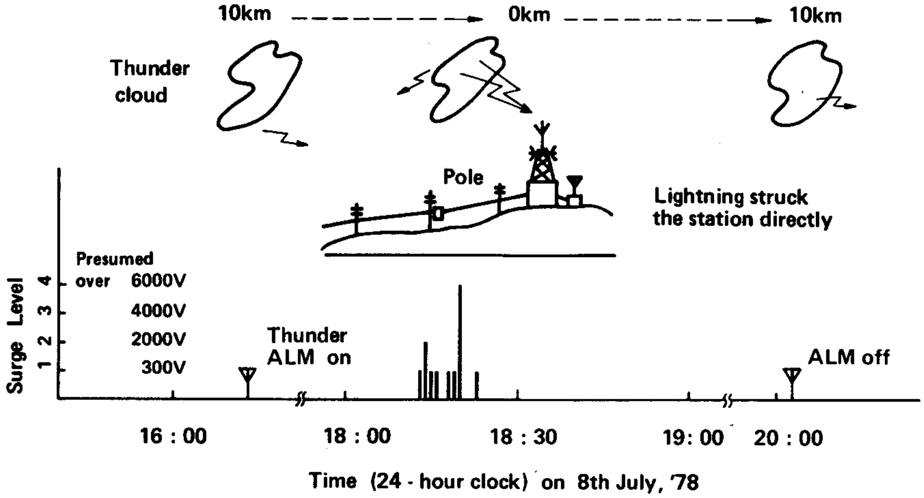

Figure 7 Detected Surge Peaks at Pole Equip.

Table 1 System Specification

Item	Specification
Optical Modulation	FM - IM
FM Frequency	10MHz ±150kHz
Bass Band	300Hz ~ 30kHz Fig. 3
Pole Equipment Supervision	Loop Back SV Signals of Optical Power and Power Supply
Optical Source	GaA/As DH -LED
Wave Length	8500 Å
Optical Detector	Si -PIN PD
Transmitter Optical Power	-20dBm
Receiver Sensitivity	-35dBm (S/N 60dB)
Fiber	Silica Core (150μm), Silicone Polymer Clad (3501μm) Nylon Jacket (1 mm), Step Index Profile NA 0.39, Loss< 6dB/km Band Width 20MHz/km
Fiber Cable	4 cores, Non Metallic with FRP Tension Member Weight 100g/m, Outer Diameter 12mm Tensile Strength < 50kg Sending Radius < 400mm
Temperature Range	-20 ~ +60°C
Dimensions of Pole Equipment	405 x 342 x 780mm x 2