A Remote Water Sensing System with Optical Fiber Networks

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***Abstract*—A remote water sensing system with optical fiber networks to be used to detect water in optical fiber splice enclosures to assure the optical transmission quality. The water sensor will adopt either one of two optical behaviors when the monitor light passes through the following heads: (1) When the monitor light is in contact with air at the sensing plane, total reflection happen, and the monitor light goes back the original optical trace to the Central Office (2) When the water sensor senses water, refractive phenomenon occurs and the monitor light can not rear back to the Central Office By this way, we can determine whether the water seeps into splice enclosures. Water sensor is very stable in normal condition and can be reused repeatedly. Applying OTDR, it can monitor up to 20 sets of water sensors on an optical fiber route. Furthermore, the water sensor can also be used in detecting the water level of a flood disaster to keep safety of equipments in the distribution cabinet and/or ensure the safety of people and vehicles through the bridge.**

Keywords- water sensor; OTDR; optical fiber networks

I. INTRODUCTION

The design principle of traditional water sensor is the application of absorbent materials, when water seeps into splice enclosure the fiber will bend and induce optical loss, by this way anybody can determinate water seeping into splice enclosure or not [1], [2], [3]. But the traditional water sensor of commercial products established in the optical fiber networks has some defects: (1) The traditional water sensors can not be used repeatedly. (2) After the sensor touching water, the insertion loss of the sensor will increase, so it can monitor two traditional water sensors in one cable at the most at the same time. And there is another sensor invented [4]. A lifetime-based fiber-optic sensor that can be used to measure water content in organic solvents and relative humidity of air is described in [5]. Optical sensor for distributed measurement of water content in soil is presented in [6].Optical fiber line testing system of traditional water sensor is referred [7].

Taiwan is located in a heavy rain zone of the earth, many man-holes are immersed in water and the splicing enclosures are submerged year after year. It will not be suitable to use in Taiwan if the water sensor is not able to detect multiple water-seeping events or not reuse again and again. Base on the described above, we have developed a new type of water sensor, which can be combined with Optical Time Domain Reflectometer (OTDR) requirement to form the whole water sensing system. Thus we create an ideal water sensing system. The water sensor device can be used repeatedly and can detect more than 20 water events distributed on an optical cable immediately. The comparison sheet of the new invention reusable water sensors & systems and the traditional commercial products are shown in Table I:

TABLE I. COMPARISON SHEET OF WATER SENSORS & SYSTEMS

Item	Reusable water sensor	Traditional water sensor
Optical monitoring requirement	OTDR	OTDR
Sensing principle	Detect return loss	Detect insertion loss
Reusable	Yes	No
Response of sensing	Immediately	About 1 hour
Events monitoring simultaneously	>20	<=2
Materials	Thin film deposited glasses	Absorbent material

The rest of the paper is organized as the following. In section II, we describe the process and the measurement of the experiments. Section III, we illustrate the design principle of the reusable water sensor, the stability of the manufacture process, and we have set up a reusable water sensing system with the Remote Fiber Test System. Finally, we make a conclusion in section IV.

II. EXPERIMENT

Requirements and materials prepared for the experiment of splicing enclosure water sensing system are as below:

- Fiber: a 1 km length of optical fiber; a 34 km length of optical fiber; and a 10 km length of optical fiber
- Reusable water sensor: 2 sets
- OTDR: 1 set
- Optical fiber fusion machine: 1 set

After the water sensing system setup for the experiment shown in Fig.1, the operation principle of OTDR water sensing system can be explained in the following steps:

Step 1: drawing the OTDR traces before water sensing by using OTDR requirement to detect the whole optical fiber networks, the trace results shown in Fig.2. From the OTDR trace drawings we can identify stronger reflection events at optical fiber distances near the places of 1 km and 35 km, the reflection loss is about 27.99 dB and 28.44 dB separately.

Besides, there is other stronger reflection peak at the end of the curve owing to the open end of the optical fiber.

Step 2: detecting the whole optical fiber networks after wetting water sensors by OTDR requirement, we obtain the drawings shown in Fig.3, from which we can see the same places in Fig. 2 with stronger reflection peaks of distance 1 km and 35 km disappeared, representing that after water sensors get wet we can not receive the measuring message at CO from detecting the water sensing networks. So, clearly we can use this method to probe the reflection events and determinate if water sensors are wet or not by OTDR.

Step 3: after the two water sensors drying we detect the whole water sensing networks by OTDR again and obtained the drawing shown in Fig. 4. By comparing Fig. 2 and Fig. 4, both the OTDR traces are almost the same, which implies the sensing messages come back to the CO again.

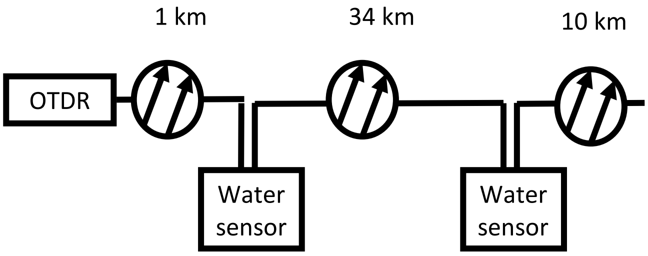

Fig. 1 Experiment OTDR water sensing system with the reusable water sensors

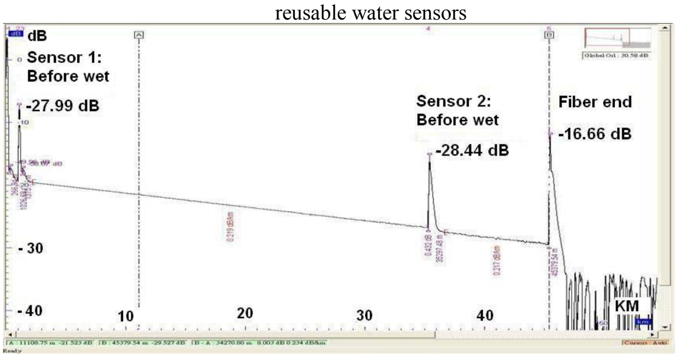

Fig. 2 OTDR traces before water sensor wet

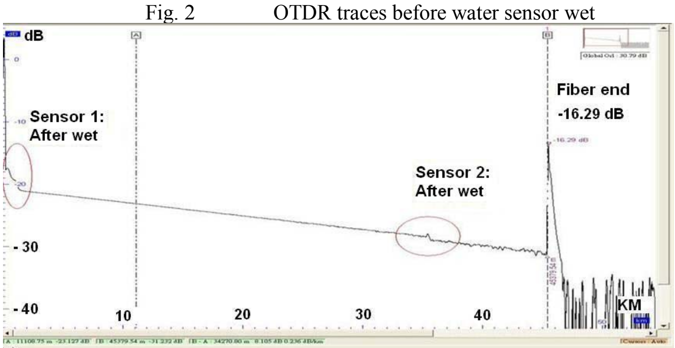

Fig. 3 OTDR traces after water sensor wet

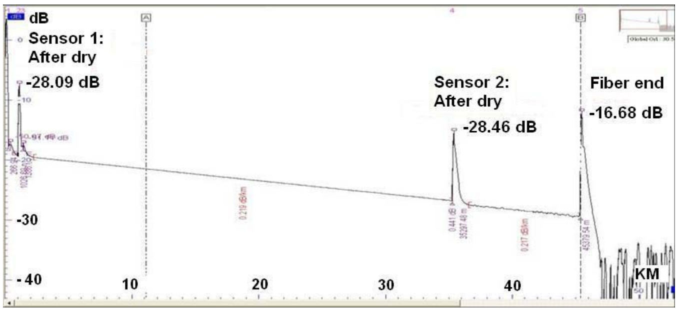

Fig. 4 OTDR traces after water sensor dried

The sensor touch water will be in a fast response manner. Once the water submerges the “Sensing Plane” of the sensor, the central office (i.e. CO) can issue an alarm message. When the water recedes, the sensor can be used again. The central office may automatically detect the reuse time, as shown in Fig.2, Fig.3 and Fig.4.

III. Results and Discussion

A. The design principle of a new invention of reusable water sensor:

Figure 5 illustrates the structure of the reusable water sensor. Both the incident angle and the refraction angle of the sensing plane are designed as 45°. The button plane of sensor is serial connected to a reflector, which in experiment can reach 99% optical reflection. Before the water sensor is wet the refractive index n of air is equal to 1. At this time, between the incident line and the normal of the laser light is 45°, and according to the Snell’s law, it meets requirement of total reflection the light goes straight to reach the reflector, and then reflect back and follow the original trace. On the contrary, after the water sensor immerses in water the refractive index changes to 1.33, the incident angle is also 45°, but at this time by the Snell’s law, it can not satisfy the total reflection condition the refractive light disappear at sensing plane. We can detect reflection power before the water sensor is wet by OTDR when the sensor has high optical reflection power. After the sensor is wet, the corresponding position of optical reflection power changes to small or even disappears. So, by detecting the return loss of the water sensor, we can determinate if it is wet or not.

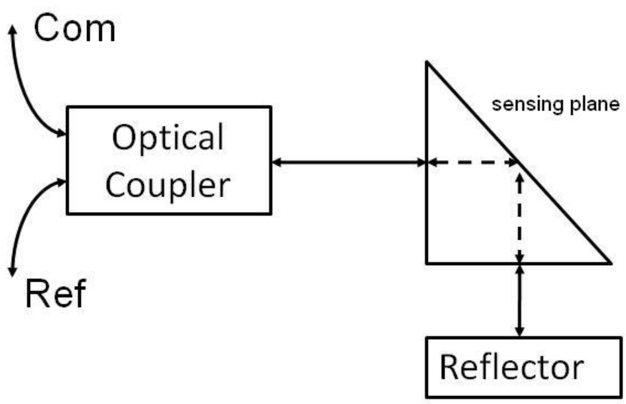

Fig. 5 water sensor structure

For the purpose of sensing the water status of multiple optical splice enclosures, every sensor may extract just a part of optical power, and owing to the consideration of the cost and the convenience of maintenance for setup the sensing system. We use a specially designed coupler with a splitter ratio calculated according to the following:

Loss=2 (OL) +WSRL; (1)

Where OL is ODN (i.e., Optical Distribution Network) loss and WSRL denotes water sensor return loss.

OL= (SL + CL) (EN) + FL; (2)

Where SL is splicing loss, CL means coupling loss, EN is equal to enclosure number, and FL represents fiber loss.

WSRL=2 (CL + SeL); (3)

Where SeL is sensor loss. Assuming a coupler within water sensor device may extract optical power by splitter ratio x, the total insertion loss of sensor assemblies is about 3dB, then formula (3) may be written as:

WSRL=2 (-10 log(x) + 3): (4)

Assuming fiber length is L, spacing between enclosures is d, the largest optical loss of two splicing points in an enclosure is 2×0.2=0.4 dB, thus, we obtain

OL= (0.4-10log (1-x)) [L/d] + 0.3L (5)

Where the function [A] rounds the elements of A to the nearest integers less than or equal to A. Then substitute (4) and (5) into (1), we obtain

Loss= 2 ((0.4-10log (1-x)) [L/d] + 0.3L) + 2 (-10log(x) + 3) (6)

By numerical analysis and assuming L=40 km, d=2 km, we obtain the smallest optical loss of the longest distance sensor for different coupler splitter ratio is about 5% shown in Fig. 6.Thus choice the splitter ratio of the coupler as 5%: 95%.

When the telecom operators setup the distributed optical fibers, they install splicing enclosures along the cables at intervals of “d” km. For calculation the number of water sensors installed in splicing enclosures as many as possible:

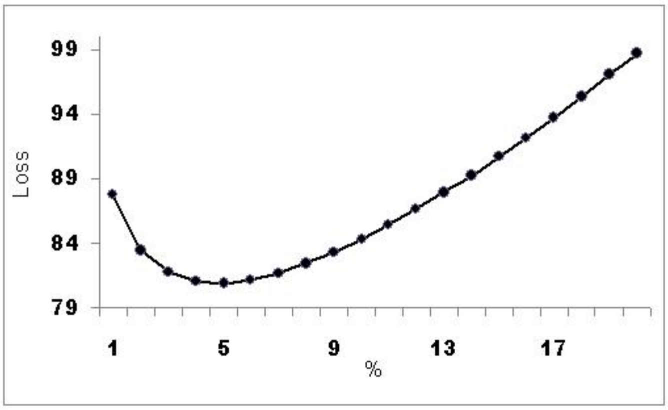

Fig. 6 splitter ratio simulation curve of couplers

Loss= (splicing loss + sensor loss) (enclosure number) + fiber loss

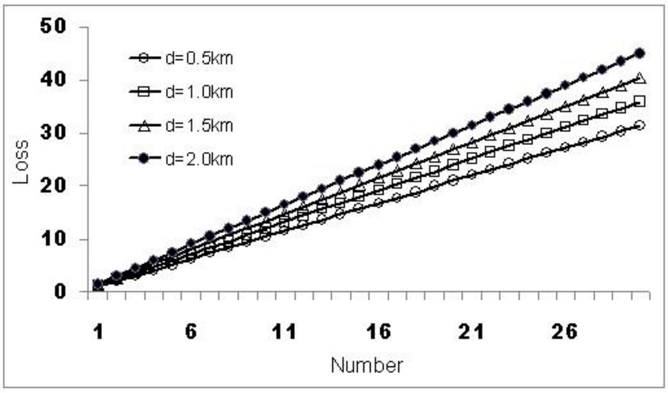

Fig. 7 simulation curves of water sensor number of a sensing system

In above formula, the largest insertion loss of a sensor is about 0.5dB, the largest splicing optical loss is 2×0.2=0.4 dB, optical loss of optical fiber is 0.3 dB per km, we can estimate the Loss= 0.9×[L/d] + 0.3×L, also by numerical analysis, we obtained Fig. 7. From Fig. 7 we find that if assumed the total optical loss is 30 dB, we can install on an optical fiber route 20 sets of sensor at least. So OTDR with dynamic range beyond 35 dB will match for a monitor system of 20 water sensors.

B. The stability of manufacture process of reusable water sensors:

The design principle of the proposal water sensor is an exciting idea from our company and we have commissioned the manufacturing company Oplink to fabricate 22 sets of the reusable water sensors. By testing the Com-Ref port insertion loss and the Com-Com port before and after wetting of water sensors separately, and calculating statistically, the average Com-Ref port insertion loss is 0.344 dB, standard deviation is 0.048 dB shown in Fig. 8. The average Com-Com port return loss before sensor wet is 30.6 dB and standard deviation is 0.8 dB shown in Fig. 9, which after sensor wet is 53.9 dB and standard deviation is 1.8 dB shown in Fig. 10 separately. From the testing results we may find that the quality of the products is very stable. The differential optical loss between before and after sensor wet is greater than 20 dB, so it is easy to differentiate whether the sensor is wet or not. The reusable water sensor can be successfully used in water sensing system.

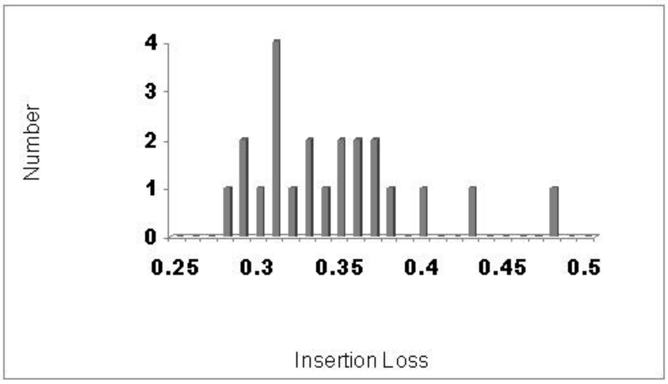

Fig. 8 Statistic diagram: Insertion Loss of Com-Ref port

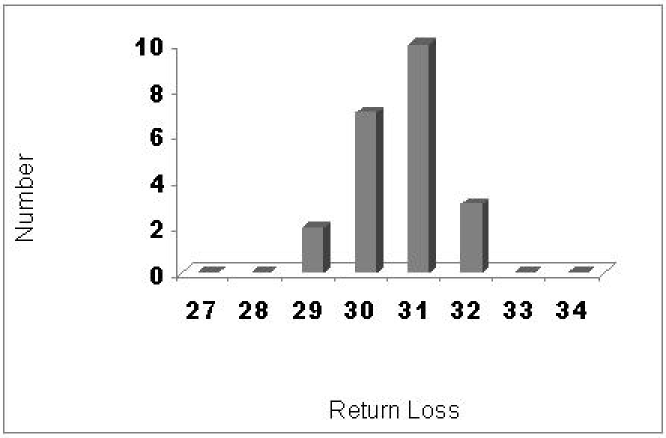

Fig. 9 Statistic diagram: Return Loss of Com-Com port before wetting of sensor

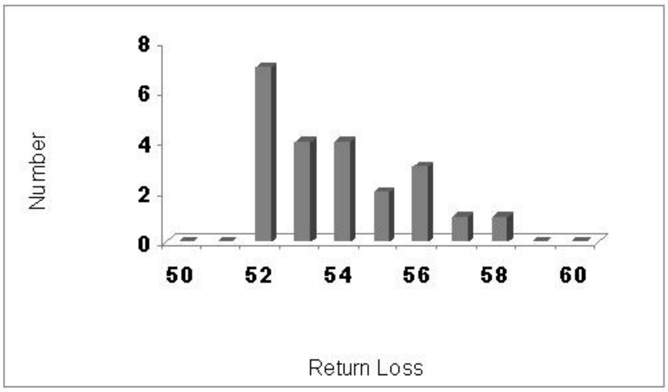

Fig. 10 Statistic diagram: Return Loss of Com-Com port after wetting of sensor

C. The setup method of the water sensing system combined with Remote Fiber Test System (RFTS):

The reusable water sensor can be applied in the optical monitoring system based on OTDR requirements. Fig. 5 illustrates that the Couplers are used in the sensor of which the light power splitter 5% into water sensor and 95% passing to the last of the cable, and 5% of the last 95% light power splitter into the next sensor and 95% of the 95% last light power passing through the last cable, and so on. When the water sensor is not wet, the OTDR shows as strong reflection peak event, when it detects water then the OTDR shows as weak reflection power event. Fig. 11 illustrates the whole optical networks and show splicing enclosures water sensing system and reveals the warning technique: several optical monitor routes of splicing enclosures are installed with water sensing devices, we select one route of fibers located at the terminals in CO connect to the fiber path selector in RTU, when detecting water the RTU monitor requirements follow the program commands and switch to the assigned fiber route, then further commanding the OTDR to start to measure and send the results back to the monitor main sever. Analyzing the characteristics of fibers and determinate the reflection status of the corresponding water sensor of splicing enclosure, if cable is at fault or splicing enclosure is wet, then a warning will be sent through public telephone networks to the maintenance people for their maintaining process right away. The warning messages and that of the precision location of the faulty place may be sent by combining technique of cell phone, E-mail and e-map. The system instruction is as below:

- In RTU, both lights from OTDR through optical path selector module and from working laser source module are coupled into the monitoring cable route with WDM, the optical power monitor module (including of optical filter module) is serial connected to the terminal of the fiber route located at another end.
- Both main light source (LS1) and supporting light source (LS2) are installed in laser light source module. When the main light source is at fault, it can be automatically switched to the supporting light source and started it. Every laser light source may monitor four routes of fibers.
- Both RTU and Main Monitor Server can communicate through IP/VPN each other. Both Main Monitor Server and terminal can communicate through IP/VPN each other, too. Terminal can collect data from Main Monitor Server or make a test to RTU.
- When the optical power monitor module of RTU detects a low power message from laser light source module, if the optical power is below the threshold power the optical power monitor module would send a warning through IP/VPN back to Main Monitor Server, then the Main Monitor Server automatically starts OTDR and optical path selector module process fiber route detected by through IP/VPN. The measurement results are sent back to Main Monitor Server again through IP/VPN.
- It may make a testing schedule of OTDR detecting.
- If it detects optical fiber fault or optical power below the threshold value or splice enclosure immersion, the Main Monitor Server starts warning process.

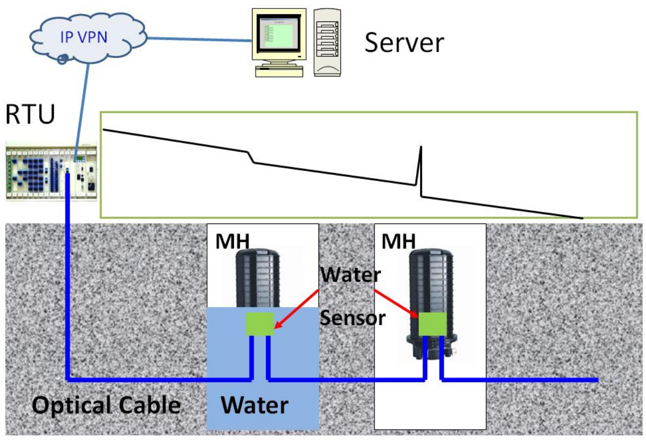

Fig. 11 Fiber line monitor main frame

Besides applied in the water sensing of optical splice enclosures in the optical fiber networks, the water sensing system may be also used in detecting water of low-lying lands. And it can be applied in the fields as listed below:

- Providing cheap and efficient solution of optical splice enclosure water sensing system, which can detect the seeping of splice enclosure immediately and can protect optical fiber from damages, promoting the utility rate of optical fiber networks.
- Providing cheap and efficient solution of water sensing of the optical cabinet immediately, it can provide a warning to move telecommunication requirements away from immersion places earlier, decreasing the loss of requirements damage.
- Providing public construction of the government organization for keeping the safety of bridges.

IV. CONCLUSION

We have developed a new type, reusable water sensing device and system, which can be set up in optical splice enclosure at distributed optical fiber networks. The reusable water sensor can detect water and the precise seeping position. The sensing system may be combined with e-map, news in brief of cell phone to announce a seeping position warning message, saving maintenance manpower and maintenance cost. Applied in the detection of water of a flooded area, the reusable water sensor can automatically probe the water disappearance status. It is a cheap and almost an ideal water sensor and can be reused again and again. So, the new type of water sensing system plays an important role in the establishment of automatically maintenance of optical fiber monitor system.

Because telecom operators take about the resources factor and cost factor into consideration, the optical splice enclosure water sensing system is often integrated with traditional RFTS in order to monitor the quality of the optical fiber loops at any time. One traditional water sensor will increase the insertion loss about 5.3~9.5 dB after wetting of water sensor, so the monitor ability of the sensing system is largely reduced [1]. Owing to different monitor mechanism of the new reusable water sensing system and RFTS, both of them can be greatly integrated.

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