Journal of Theoretical and Applied Information Technology
31st May 2015. Vol.75. No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

OPTICAL POWER ATTENUATION OF LONG DISTANCE OPGW IN MALAYSIA

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ABSTRACT

Thousands of kilometres of Optical Ground Wire (OPGW) have been installed by electrical utility companies for two main purposes which are telecommunication and grounding. As the demand of optical fibres keep increasing to fulfil the needs for long distance communication that is immune to weather, telecommunication companies prefer to lease the extra fibres from electrical utility companies. Unfortunately, bend of optical fibre contribute to the loss and attenuate the optical power. High optical power attenuation found after several months of cable installation and caused the system to be interrupted. In this paper, the attenuation of optical fibres of long OPGW is monitored and discussed. The monitoring activities have been done on installed OPGW cable belongs to an electrical utility company, Tenaga Nasional Berhad (TNB) of Malaysia to determine the attenuation of optical power in 10 months.

Keywords: *Optical Ground Wire (OPGW), Optical Fibre, Optical Power Attenuation, Wavelength, Mode Field Diameter (MFD), Bend Loss*

1. INTRODUCTION

Optical power attenuation is a usual phenomenon in optical fibre industries. The attenuation might be caused by absorption [1], scattering [1][2][3], dispersion[4][5], bending[6], core and cladding [7], splicing and connectors [8]. The attenuation for 1310 nm wavelength for long distance is given by 0.35dB/km while 1550 nm wavelength is 0.23dB/km [9]. Before the OPGW was installed on the high voltage transmission tower, the cable was tested in the factory before being transported to site.

Unfortunately, the condition of testing process is not similar with the actual installation on site. The attenuation can be affected by temperature since the outer layer of OPGW cable is made from aluminium and alloy [10] and the optical fibres are closely contacted with the stainless steel tube [11]. Since the heat due to faulty current and lightning strike will be dissipated along the link [12][13], the heat will transfer from layer to layer till it reaches the optical fibres that have different capability of heat transfer [14].

Even though there is test conducted to measure the effect of high temperature on attenuation of optical fibre [12][13][14], the result does not exactly represent the actual condition of the installed OPGW on high voltage transmission towers. Thus, in this study, the attenuation of the existing OPGW cable was studied in 10 months to observe the attenuation performance.

The monitoring of attenuation in a set of time is to determine the optical power performance. The performace might be affected by several factors, but in this study, the level of attenuation is compared with the maximum allowable value of attenuation for that link. The study will examine the reliability of OPGW as long distance telecommunication backbone and to discuss the possible factors that contribute to the findings.

2. OPTICAL POWER & ATTENUATION

Experiments have been conducted to see the optical power attenuation of OPGW cable. The existing cable of OPGW with the length of 54.554km that was installed on a 275kV

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

transmission tower has been chosen as the tested cable. There are 24 joining points that connect each segment of OPGW where each of them is enclosed by the joint closures.

2.1 Optical Power

The experiment has been done using Power Meter tool sets to measure the attenuation of power that is injected from the Power Source to the optical fibre. The optical power is measured using Planck–Einstein equation [15].

$$E = hv \quad (1)$$

Where *h* is Planck constant (6.623 X 10-34 Joule seconds or 4.14 X 10−15 eV seconds) and v is the frequency of the energy associated with electromagnetic wave. The frequency of energy is given by:

$$v = \frac{c}{\lambda} \quad (2)$$

where c is the speed of light (2.998 x 108 ms-1) and λ is the wavelength of light. Hence, the relationship of energy, E and wavelength, λ is presented as Equation 3

$$E = h\frac{c}{\lambda} \quad (3)$$

Then, to convert the energy in Joules to the power in watt, W the Equation 4 is used.

$$W = \frac{J}{t} \quad (4)$$

From this equation, energy is inversely proportional with the length of light wave and the power is a rate of energy in joule in one second, which has a direct proportionality relationship.

2.2 Power Attenuation

The attenuation of fibre optic is the measuring of loss in dB that is encountered by light by the ratio of power. The input power in miliwatt is measured at the end of the fibre as the output is also in miliwatt. The conversion in term of dB is using the Equation 5 [16].

$$dB = 10 \times \log(\text{Optical Power} / 1\ \text{mW}) \quad (5)$$

Multiple contributions to an overall transmission value arise from the intrinsic fibre material properties as well as attenuation mechanisms associated with fibre fabrication (preform development, drawing conditions). These different processes add to the observed reduction in transmitted power (P(z)) through the contributions to the magnitude and wavelength dependence of α total [17].

The overall optical throughput (transmission) of an optical fibre can be quantified in terms of the input optical power, P(0), and the output power, P(z) observed after light propagates a distance, z, along the fibre length. The relationship is shown in the Equation 6 and 7.

$$P_{(z)} = P_{(0)} e^{-\alpha_{total} z} \quad (6)$$

Where α total is the total attenuation coefficient involving all contributions to attenuation. The equation is referred to as Beer's Law and shows that transmitted power decreases exponentially with the propagation distance through the fibre.

$$\%T = \frac{P_{(z)}}{P_{(0)}} \quad (7)$$

%T is the percentage optical power transmission. It is important to note at the outset, that %T is an extrinsic measure of the ability of the fibres to transmit optical power. In an optical fibre transmission context, the attenuation coefficient which has been discussed earlier is often expressed in base-10 form as Equation 8 and Equation 9.

$$\alpha_{total}\,(dB/km) = \frac{10}{z} \log\left[\frac{P(0)}{P(z)}\right] \quad (8)$$

$$\alpha_{total}\,(dB/km) = \frac{10}{z}\left(\log P_{(0)} - \log P_{(z)}\right) \quad (9)$$

$$\alpha_{total}\,(dB/km) = 4.343\alpha_{total}\,(km^{-1}) \quad (10)$$

Since in this measurement, the total attenuation will be analysed without concerning on attenuation coefficient (dB per km), the formula can be expressed as

$$\text{Attenuation, dB} = P_{in} - P_{out} \quad (11)$$

Where Pin is the input power measured during calibration process and Pout is the value captured at the end of fibre link. This final parameter is often referred to as the "fibre loss".

2.3 Maximum Allowable Loss

The quality of the fibre is then compared with the value of Maximum Allowable Loss [9], MAL for that link and has to be calculated by using the Equation 12.

$$\text{MAL, dB} = \alpha(d) + \beta(n_1) + c(n_2) \quad (12)$$

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Where α is the cable loss, dB/km which depends on the wavelength used. d is the distance (km) of the fibre cable while β and c is splice loss and connector loss in dB respectively. n1 and n2 are the number of splice and connector along the link. These values which are 25.122dB for 1310 mm and 16.939dB respectively for 1310nm and 1550nm then will become the benchmark where from one experiment to another, the margin loss between MAL and attenuation get from experiment will be monitored and analysed.

3. EXPERIMENTS

Power meter will be used to test on five samples with 1310 nm and 1550 nm wavelengths. Three experiments have been done within 10 months where the first experiment was done on January 2013, second experiment on July 2013 and the last experiment was conducted on October 2014. All of these experiments have been done on the existing OPGW with the distance of 54km and 23 units of joint closures from Batu Pahat to Yong Peng. The purpose of these three experiments is to measure the attenuation of both wavelengths where they have different sensitivity on loss especially bend loss [18][19].

The calibration process has to be done in every experiment. After the calibration process has been done, the testing could be done with those two patch cords used in calibration remain used during the experiment. This step then will be repeated for all the five samples. The same method will be implemented on three experiments that will be done in a duration of 10 months. The results of the power meter test are shown in Table 1 for 1310 nm and Table 2 for 1550 nm respectively.

Table 1: Attenuation of 1310 nm wavelength

Sample	Attenuation (dB)		
	Exp. I	Exp. II	Exp. III
1	19.923	20.113	20.100
2	19.975	20.200	20.119
3	19.619	19.998	20.003
4	19.914	20.089	20.104
5	20.242	20.331	20.300

Table 2: Attenuation of 1550 nm wavelength

Sample	Attenuation (dB)		
	Exp. I	Exp. II	Exp. III
1	14.473	17.888	19.226
2	14.151	17.846	19.232
3	14.587	17.903	19.221
4	14.532	17.797	19.099
5	14.448	17.911	19.172

Since the values of attenuations vary, the mean of all five samples will be calculated by using the Equation 13 and tabulated as in Table 3.

$$\text{Mean Attenuation} = \frac{\Sigma \text{Attenuation}}{\text{Number of Samples}} \qquad (13)$$

Table 3: Mean Attenuation of 1310 nm and 1550 nm wavelength

Sample	Attenuation (dB)		
	Experiment I	Experiment II	Experiment III
1	19.935	20.146	20.125
2	14.438	17.869	19.190

The monitoring on the attenuation of fibre using both wavelengths is present as in Fig. 1 and Fig. 2 respectively. From the observation on Fig. 1, the attenuation of 1310 nm shows an increment but with the minimum effects. The margin of MAL1310 is acceptable which is about 5dB for the current performance. The proposed margin is 6dB as in [9].

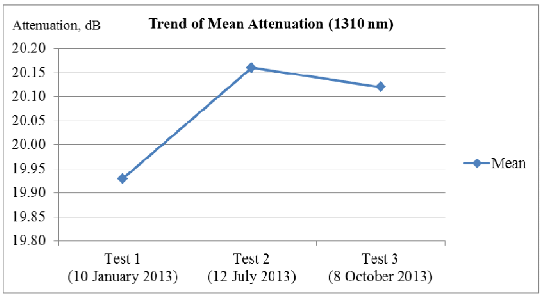

Figure 1: The performance of fibre using 1310 wavelength

The 1550 nm shows a major increment of attenuation and has exceeded the value of MAL1550 mark as dotted line before the Experiment II.

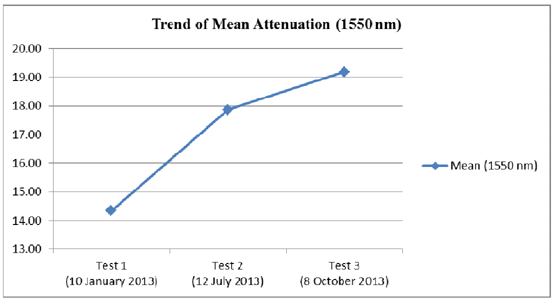

Figure 2: The performance of fibre using 1550 nm wavelength

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The increment of attenuation monitored by 1550 nm as shown in Fig. 2 is significantly observed. This activity indicates that the fibre has encountered problematic issue and the factor that contributes to this decrease of performance is discussed in the next segment.

4. DISCUSSION

From the results obtained through the experiments, different trends are observed between attenuation of 1310 nm and 1550 nm wavelength. The difference of these two trends are shown as in Fig. 3.

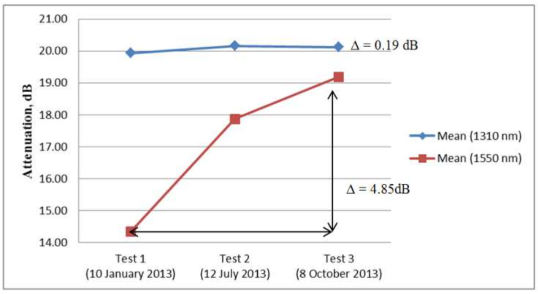

Fig. 3 The different trends of attenuation between 1310 nm and 1550 nm.

There is only 0.19 dB increase of attenuation encountered by power of 1310 nm wavelength while power of 1550 nm wavelength has attenuated by 4.85 dB in the same duration of 10 months. This trend indicates that, 1550 nm wavelength has been affected more by the losses that contribute to this problem.

4.1 Mode Field Diameter

Many types of losses that can be contributed to the increase of attenuation of optical power. As discussed by [18] and [19], the losses that have different capability in affecting the different wavelength are bending losses.

The single most important factor that determines the susceptibility of a fibre to macro bending induced loss is the Mode Field Diameter (MFD). MFD represents the area in which the light goes through and includes the core and a part of the cladding. A smaller mode field diameter indicates that light is more tightly confined to the fibre centre and, therefore is less prone to leakage when the fibre is looped [20]. Figure 3 shows the relationship of light power and MFD where diameter of core and the wavelengths are the important parameters in determining the sensitivity of macro bend loss.

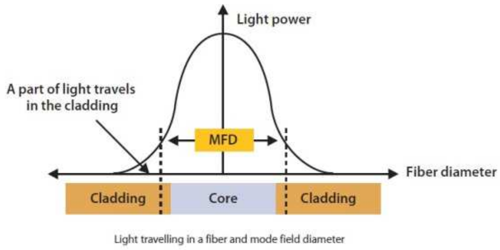

Fig. 3 The relationship between light and MFD

The total number of modes supported in a curved, multimode fibre is therefore related to the index profile, the propagating wavelength, and the radius of curvature as shown in Equation 14.

$$N_{eff} = N_{\infty}\left\{1 - \frac{\alpha + 2}{2\alpha\Delta}\left[\frac{2\alpha}{R} + \left(\frac{3}{2n_2kR}\right)^{2/3}\right]\right\} \quad (14)$$

Where N∞ is the number of modes supported in a straight fibre, α defines the index profile, Δ is the core-cladding index difference, n2 is the cladding index, k = 2π/λ and R is the radius of curvature of the bend [7].

However, single mode fibre has a larger mode field diameter at 1550 nm than at 1310 nm and at 1625 nm than at 1550 nm. Larger mode fields are sensitive to lateral offset during splicing, but they are more sensitive to losses incurred by bends during installation or in the cabling process [18]. 1550nm is more sensitive to bends in the fibre than 1310nm. This is termed as macro bending.

5. CONCLUSION & RECOMENDATIONS

The attenuation of fibre optic has shown increment as times goes. The power attenuation shows an increase significantly by using 1550 nm where the fibre attenuation has exceeded the maximum allowable loss of maximum attenuation of the fibre in 10 months of experiment. At this level, the fibre could not be used for transporting data for communication purpose anymore for those communications that use 1550 nm as their preferred wavelength.

Further studies on the overall performance of the optical fibre on attenuation have to be conducted to ensure the factors discussed in this paper are proven. Longer wavelength might be used such as 1625 nm for comparison as future technology of Dense Wavelength Division Multiplexing (DWDM) will be widely implemented. In additional, the relationship between bend loss and optical power attenuation on long distance optical fibre have to be developed in order to determine the reliability. There is limited study on the comparison of those mostly used wavelengths which are 1310 nm, 1550nm and 1625 nm particularly on the effect of bend loss and its relationship on optical power attenuation. This is important to understand what has contributed to the increment of attenuation as time goes and to find the solution to this problem.

ACKNOWLEDGMENT

The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for supporting this work under the research grant, PJP/2013/FKEKK(2B)/S01131.

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