

Tracking fault of distribution single core underground power cable by FBG wavelength

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This paper presents on FBG Code Supervision into Single Core Underground Cable Power Line for Health Condition. Fiber Bragg Grating (FBG) is a novel technique for network health monitoring, offering numerous advantages such as high precision, multiplexing capabilities, resistance to electromagnetic interference, and excellent repeatability. The FBG sensor integrated into the network has been employed in numerous applications to monitor system and environmental conditions. Any interruption on the system or environment can be sensed and monitored through the status of network health. A consistent Fiber Bragg Grating (FBG) array situated before and after the splitter will be utilized to reflect the optical signal that has been transferred along the fiber. As the network's FBGs use different wavelengths to represent each line connection, FBG codes will serve as an indicator between one connection to another. In this paper, a new technique is shown to monitor network health for single core underground cable by developing fault branch identification FBG configuration designs (FBG codes) up to 36 branches while maintaining quality of power transmission. Its capabilities are confirmed by simulations using real model data and it shows the potential to solve the various problems presently we have.

Keywords: network monitoring, Fiber Bragg Grating, codes, underground power line, XLPE

1 Introduction

Electric power companies prioritise the provision of a secure and consistent electrical power supply. The initial concern to be addressed during the evaluation of numerous safety measures is prevention of electric leakage and break in the power line. Supervisory communication pilot cables of better known as pilot cables have been used in power supply provider for the unit protection scheme, communication channel for tool control and SCADA purposes [1, 2]. The pilot cable is usually located in underground next to the underground power cable. The pilot cable has been extensively used since the 1960s. Currently there are two types of pilot cable used in the distribution system which are 12 pairs and 37 pairs for 11kV and 33kV system respectively [3], [4].

Since records of the pilot cable routes are not well maintained and updated, most of the cable routes are unknown. In addition, there does not have a specific equipment to identify the exact location of the cable fault along its route. Thus, no technique to pin-pointing the exact location of pilot cable faults, a trial-and-error method is practiced on sites by digging the estimated

location given by TDR. This trial-and-error method requires longer time and higher cost for pilot cable repair because a multiple number of locations are dug before the exact location can be accurately determined.

With the modern cable transmission system that embedded with optical sensor will be solved those issues. Thus, implementation of new modern cable transmission will preserve environments indirectly less of maintenance costing. It is also can remotely monitor cable faulty in the real time and improving the quality performance of delivery power without electromagnetic interference distortion [5]. Furthermore, expectation delivery data information along distributes underground power cable would be phenomenon in future later.

2 Underground power line transmission environment

2.1 Single core 11/33 kV cable

Normal arrangement of single-core underground transmission line is used separately as shown in Fig. 1. Usually, this layout cable will connect to 11 kV/33 kV busbar before delivered to end point.

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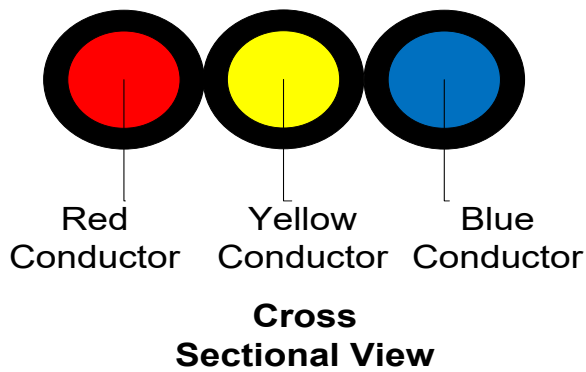


Fig. 1. Indicative cross section single-core power transmission line

2.2 Conventional arrangement single core 11/33 kV cable

Figure 2 shows the arrangement of the underground power line with optical or communication cables laid alongside in one trench [6].

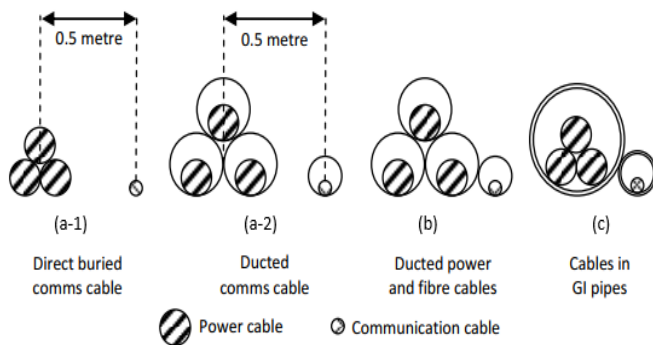


Fig. 2. Cross-section view of communication power cables laying arrangement

- For direct-buried and ducted cables, the distance between the communication cable and the power cable should be at least 0.5 meter apart to reduce electromagnetic disturbance on the communication cable.
- Optical cables in ducts can be in contact with power cable ducting.
- For cables installed in galvanized iron (GI) pipes, the GI pipes for the communication and power cable can be in contact with each other.

2.3 Cross linked polyethylene insulation power

The power cable with cross-linked polyethylene insulation (XLPE) is currently a widely used technology for high voltage (110 kV) and ultra-high voltage (230 and 330 kV) [7, 8]. The cable will act as multipurpose such as supply power, cover communication and network monitoring. The main issue is due to high costs for

producing XLPE cable and cost repairing or maintenance in the case of emergency failure. An XLPE cable with an optical fiber buried in the insulator cable is shown in Fig. 3. Since each individual cable is attached to an optical fiber cable (OFC), which is immune to electromagnetic interference (EMI), the amount of magnetic flux caused by a power line would be insignificant [9].

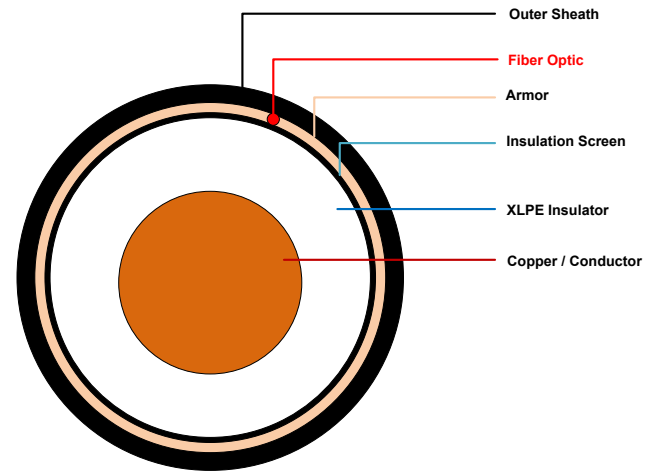


Fig. 3. Cross sectional view of XLPE cable

2.4 Electricity supply network

The power distribution network includes medium and low voltage power lines and cables, substations, switching stations and metering system. Typical medium voltage in the network is 11 kV and 33 kV [10].

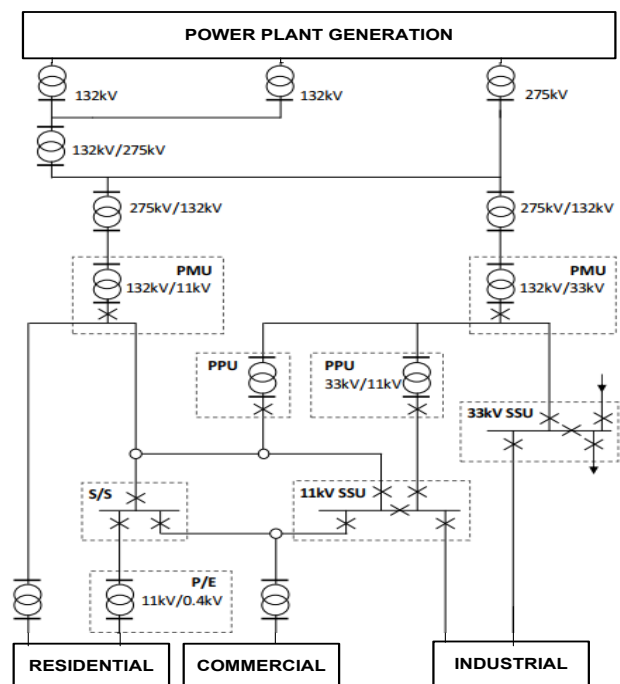


Fig. 4. Single diagram electricity network

Figure 4 shows the delivery of electricity from the transmission network to end users. Distribution substations consist of equipment such as transformers and circuit breakers, and are interconnected by a network of underground cables and overhead power lines. There are several types of distribution substations which can either be of outdoor or indoor design, and either stand-alone or attached to a building.

3 Working principle of FBG

Due to ability of reflecting light, Fiber Bragg Grating (FBG) is widely used for low-cost optical filter in the monitoring system. The only particular wavelength is reflected back when the light delivers to the FBG sensor [11].

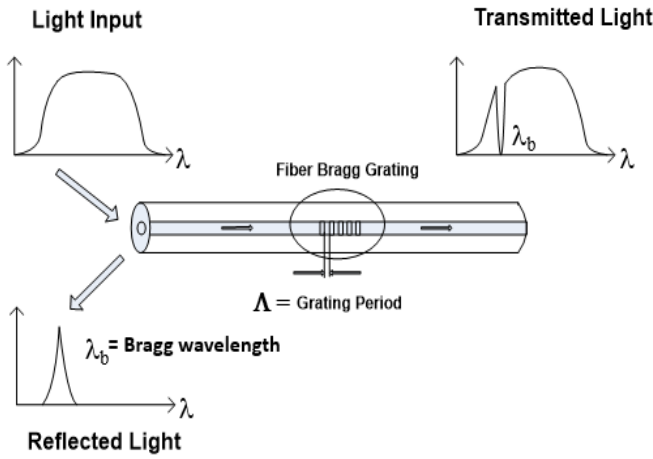


Fig. 5. Mechanism of FBG sensor

This light's Bragg's wavelength, also known as its centrally reflected wavelength spectrum, can be characterized as [12]

$$\lambda_b = 2n_{\text{eff}} \Lambda. \quad (1)$$

Here, n_{eff} is the effective refractive index and Λ is the spatial period or period of grating [13].

Figure 5 shows the concept of FBG sensor's mechanism. The optical spectrum analyzer (OSA) will analyze the reflected spectrum using FBGs as branch or fiber indicators placed at each ONU [14]. FBG is widely used in OCDMA code generation, filtering, and amplifier gain flattening.

4 Methodology

4.1 Proposed monitoring power transmission structure

A white light source is used as a monitoring signal which is combine with downstream signal in FBG monitoring system by multiplexer [15]. Utilizing the existing fiber inside the cable (XLPE cable) or laying the fiber along underground power line is the best method to decrease the costing or installation and maintenance in future as shown in Fig 6. Fiber will attach together with power line for each fractional until to end user as discussed in Fig 4. A multiplexer along the fiber has been employed to combine downstream signals with a white light source as a monitoring signal. The laser-transmitted signal will be transformed into individual fiber fractions by an optical splitter. Every fiber fraction will be positioned in several homogeneous FBGs with distinctive spectrum reflections at different wavelengths and bandwidth.

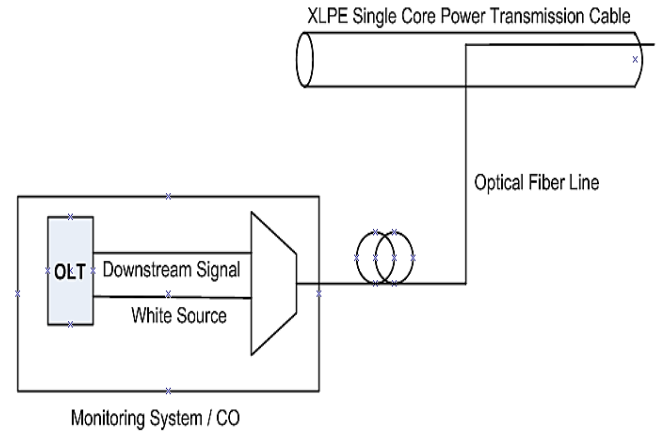


Fig. 6. Monitoring power transmission line using optical fiber network (dark fiber)

The FBG code will be generated to indicate every line, in combination with the DP number and port number. Taking advantage of the monitoring signal, the FBG will produce reflections light according to the specified wavelength, reflection, and bandwidth parameters developed at the FBG [17-19]. The FBG spectrum reflection can be used to detect the unique code that is generated to differentiate each port. OSA has been used for monitoring and investigating these spectrum reflections to make sure that each signal transfer to each port is still working properly as shown in Fig. 4.

4.2 Power network fault monitoring system

The selected Bragg wavelength is from 1601.0 nm to 1604.9 to represent for the branches. The final two integers can be used to represent the distribution point and decimal point will be as an optical network unit.

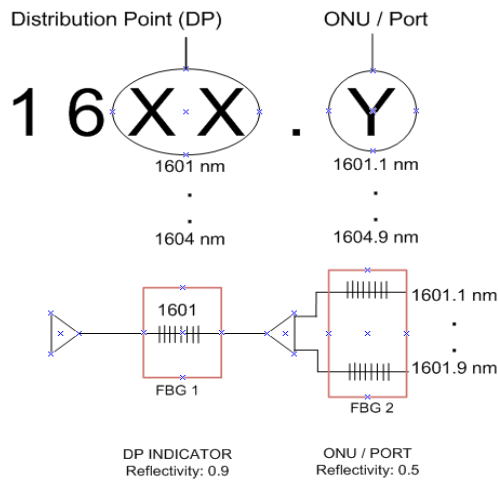


Fig. 7. FBG design configuration in network fault

The design configuration for FBG is shown in Fig. 7. The distribution point and ONU may be quickly identified by looking at the specified FBG wavelength. The first FBG is used as indicator for distribution point which have a 90% reflectivity. The second FBG with 50% reflectivity is setup to portray the ONU [19]. The basic working principle for this monitoring technique is depicted in Fig. 8. In this monitoring, three downstream signals at 1310 nm, 1490 nm and 1550 nm wavelength will combine and propagate together with the monitoring or white source at 1620 nm wavelength to avoid any traffic interference with monitoring signal [20].

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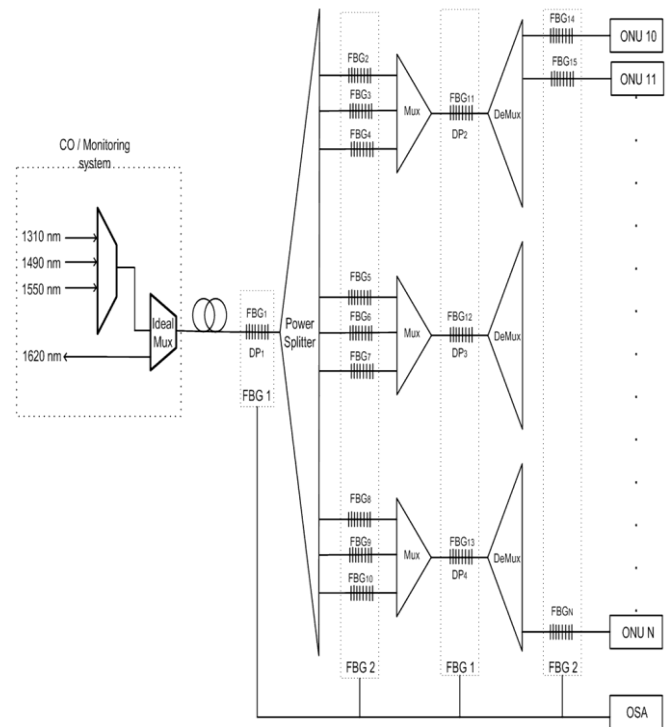


Fig. 8. Block diagram of supervisory network power line monitoring for single core cable

Table 1. Inventory of the Bragg wavelength by each FBG

Wavelength FBG 1 (nm)	Distribution point (DP)	Wavelength FBG 2 (nm)	ONU/No. PORT
1601	1	1601.1	1
		.	.
		1601.9	9
1602	2	1602.1	10
		.	.
		1602.9	18
1603	3	1603.1	19
		.	.
		1603.9	27
1604	4	1604.1	28
		.	.
		1604.9	36

The centre wavelength 1620 nm is used for downstream signal representing L Band which is wavelength range from 1565 nm to 1625 nm. The unused spectrum is used for monitoring started from 1601 nm. Each of optical power signal is using 0 dBm. A merging traffic signal with monitoring source into network occurs by WDM multiplexer and move down to ideal multiplexer. The traffic signal will transmit along the optical cable till power splitter. At this point, the power of each distribution or ONU will be drop.

In the simulation, each of FBG will be dedicated with the wavelength as shown in Tab. 1. The monitoring or white source will reflect the Bragg wavelength based on the unique FBG wavelength and it is used to monitor reflected wavelength FBG for the 36 ONU or branches. Optical spectrum analyzer (OSA) is exploited to observe the bounce wavelength in the network. In general, two type of FBG is consumed FBG 1 and FBG 2 also shown in Fig. 8. Total FBGs for this network can be calculated as

$$\text{Total FBGs} = DP_N + (DP_N \times 9),$$

where DP_N is the total number of distribution points in the network. For 36 ports or branches, 40 FBGs is applied for this monitoring system.

5 Results

The simulated monitoring system is analyzed in this section by using OptiSystem simulation software. Simulation design is created as shown in Fig 8. Generally, the reference downstream input is 1550 nm with 0 dBm input power going through 17 km optical fiber with 0.2 dB/km applied. Thus, $0.2 \text{ dB/km} \times 17 \text{ km} \times 2 = 6.8 \text{ dB}$ is the attenuation loss for the optical fiber. Table 1 illustrates the wavelengths of all FBGs, starting from 1601.1 dBm at the first ONU to 1604.9 dBm at the thirtysixth ONU. All FBGs are the ideal FBGs with zero loss. In this simulation, a 1×9 power splitter with zero loss is applied and the power will be evaluated for the first thirtysix ONUs.

Figure 9 illustrates the downstream power received against branches of ONUs. The subsequent power received decreases as the quantity of ONUs rises. From the Fig. 9, the downstream power received from 20 ONUs to 36 ONUs is almost -20 dBm . The least observable monitoring power for 36 ONUs is -19.99 dBm .

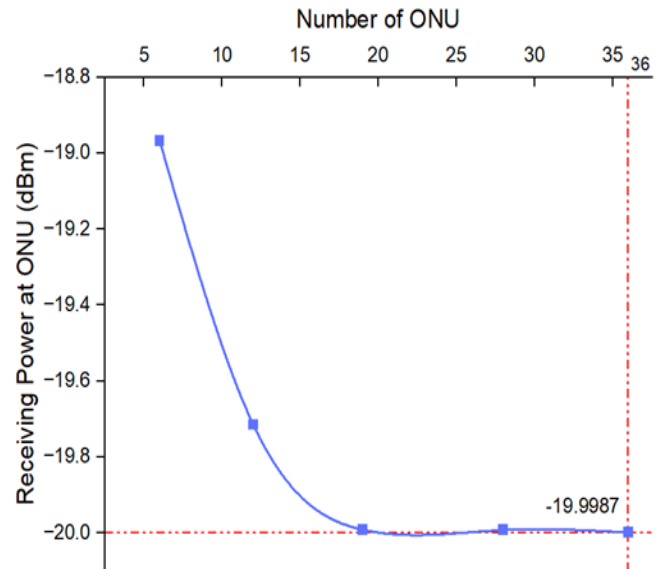


Fig. 9. The received downstream signal power in relation to the quantity of ONUs

Figure 10 shows the receiving power at a particular branch in normal and fault condition concurrently in a network using OSA. Analysis shows that when a fault occurs in the network, receiving power will degrade as depicted in Fig. 10.

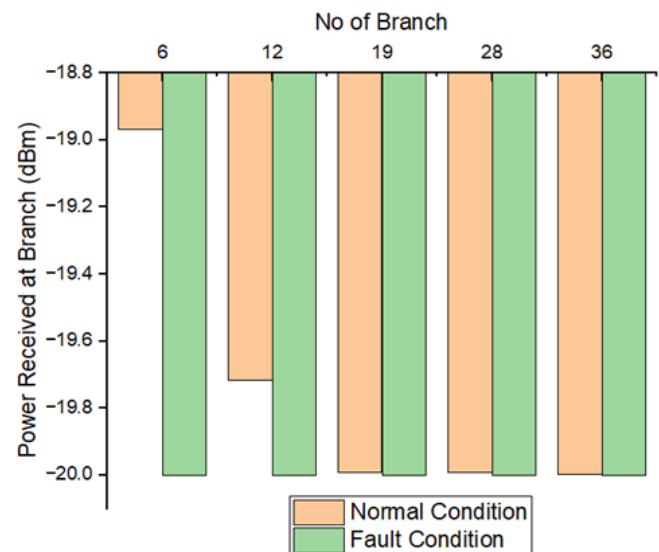


Fig. 10. Power received at particular branch during normal and fault condition simultaneously

Under fault condition, the power receiving at branch #12 dropped to -20 dBm instead of -19.7154 dBm in normal condition. At branch # 36 the dropping receiving

power slightly different around -0.01 dBm from normal operation network. This indicates that one of the branches has problem and is unable to send power ideally.

The monitoring signal is utilized to evaluate the condition of fiber which is attached together with the underground powerline and the spectrum is analyzed by optical spectrum analyzer (OSA) at monitoring receiver. Figure 11 shows the FBG wavelength reflection for each ONU. Figure 11 indicates that every ONU in the power line network can be monitored closely by assigning unique wavelength in normal operation. Power of the monitoring signal diminishes as the ONUs increase. As mentioned earlier, FBG 1 (1601 nm, 1602 nm, 1603 nm and 1604 nm) will be the distribution point, while FBG 2 (1601.x, 1602.x, 1603.x and 1604.x) are the ONUs. In this simulation, power attenuation is applied at the ONU#24 before FBG 2 with 50 dB. As a result, monitoring power received for 36 ONUs shown in Fig 12.

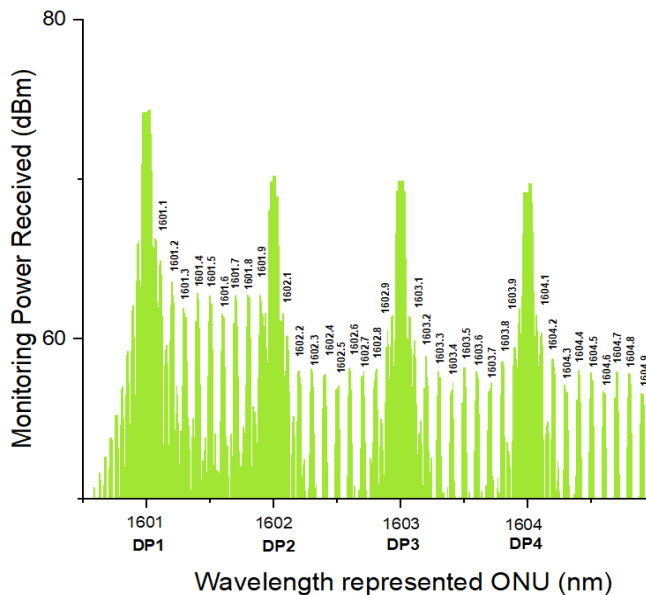


Fig. 11. Monitoring power received for each branch without fault analysis by OSA

The reflection spectra of the FBG do not accurately present on the ONU#24 in OSA analysis which is 1603.6 nm. This difference is clearly visible after the implementation of the power attenuator, whereas previously the ONU#24 was noticeable.

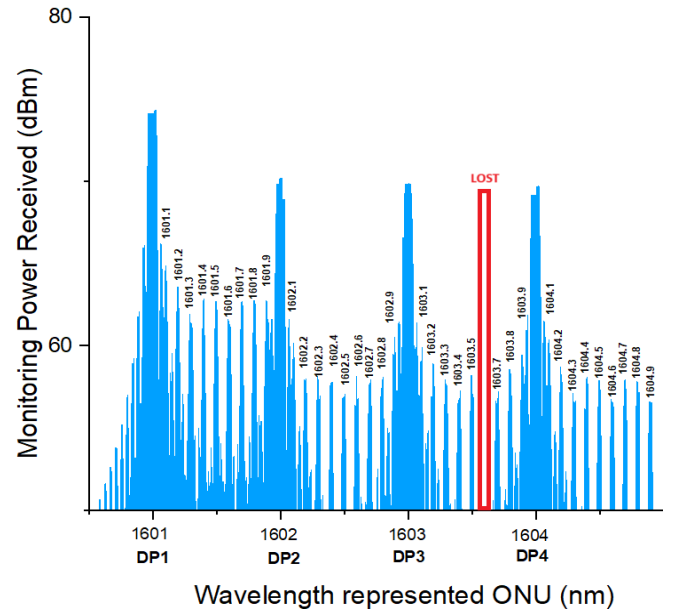


Fig. 12. Monitoring power received for each branch and fault at 1603.6 nm and analysed by OSA

Based on simulation result analysis, it indicates that this monitoring technique is straight forward technique. Using unique FBG coding created by reflected FBG spectra without neglected on quality power receiving. This method is efficient approaching due to minimum numbers of component and low impact on power budget. It can be summarized that this monitoring system may oversee up to 36 ONUs or underground powerline utilizing OSA as monitoring component. The downstream signal power received for 36 ONUs is -19.99 dBm and monitoring power received around 70 dBm. Nevertheless, system performance monitoring can be enhanced by employing actual loss and expand to huge network comply with the power line network.

6 Conclusion

In conclusion, the simulation setup for powerline monitoring in tree diagram network used FBG codes has been established. An FBG was placed at each distribution fiber which is every reflection spectrum from them will be used as references to recognize the fiber/branches by assigning FBG codes. The FBG spectrum was inspected with an OSA and any absent reflection spectrum signified a defective fiber or branches. Reflection of spectrum FBG, bandwidth and Bragg wavelength were applied as the monitoring source. Analysis revealed that this method was able to supervise 36 ONUs/branches, until 700 ONUs/branches

with receiving power -19.99 dBm, which complies with the FBG concept. This supervision system technique is quite efficient since low component involve without degrading the power and performance of the network. Furthermore, maintenance and equipment cost can be decrease whenever used existing fiber inside the power line cable itself.

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