Design Optical Fiber Networks Over Electrical Power Transmission Line Infrastructures In Kurdistan Region of Iraq

Aluminum Tube Layer Warping Core Type OPGW

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Contents

1. Abstract:

In order to fully utilize the 132 KV power transmission line infrastructures in KRG, we have designed an optical fiber network overlaying it, taking into account both current and anticipated future traffic demands. The network includes the installation of optical power ground wire (OPGW) with 36 fibers, and the architecture supports 32 DWDM wavelength channels operating at 10 Gb/s each. Additionally, Ethernet switching and impairment awareness features have been incorporated into the optical network to enable rapid switching and enhance robustness.

2. Introduction

In the Kurdistan Region of Iraq (KRG), the current infrastructure of 132 KV overhead power transmission lines primarily incorporates earth wires for lightning protection. Communication and protection functionalities rely on power line carriers (PLCs), telephone exchanges, and remote terminal units (RTUs). The Ministry of Electricity's employees predominantly rely on privately owned wireless networks for communication. Integrating optical power ground wire (OPGW) with the existing power transmission line infrastructure can efficiently connect substations and towns at a low cost, offering economic benefits.

The 132 KV power transmission line system under discussion in this paper stretches from Erbil to Sulaymaniyah, passing through two Sub Districts: Koya and Dukan. The decision to utilize the 132 KV system was based on its route, which includes multiple substations and towns. This project forms part of a broader initiative to establish a national optical network spanning all of KRG, anticipating a significant increase in network traffic in the near future. Consequently, the network's scalability is essential to accommodate this anticipated growth.

3. Engineering of optical power ground wire (OPGW)

3.1 Type of OPGW

When we use standard single mode fiber (SSMF), we must also use chromatic dispersion compensation fibers (CDCF) to make up for the dispersion that builds up. SSMF has chromatic dispersion (CD) ranging from 17-18 ps/nm.km. If we suppose that CDCF has a CD of 170 ps/nm.km, then its length will be 1/10 of the length of SSMF. If the SSMF length between two substations is 100 km, then we need to use 10 km CDCF. To make this happen, the CDCF needs to be laid from the tower to the communication room for about 200 m, and then wired back and forth many times. CDCF usually has nonlinearity effects, so it's better to use it where the signal is weak at the receiver's side. That's why we chose low dispersion fiber, known as non-zero-dispersion-shifted fiber (NZ-DSF). According to the ITU-T G.655 standard, NZ-DSF has a CD of about 3-4 ps/nm.km. The maximum length of our project is 100 km. If we assume that NZ-DSF fiber has a CD of 4 ps/nm.km, then the total dispersion will be 400 ps/nm. According to the ITU-T G.655 and Anrisu, the maximum distance that an optical signal can be sent through an optical fiber without using chromatic dispersion compensation is calculated by the formula: $L= 104{,}000/CD.B^2$, where L is the distance in km, CD is chromatic dispersion in ps/nm.km, and B is the bit rate in Gb/s. For a CD of 4 ps/nm.km and B of 10 Gb/s, we can get a distance of 260 km. If CD is 3 ps/nm.km, then the distance is 347 km. This shows that we do not need chromatic dispersion compensation in our project. The 36 fibers are divided into six groups evenly and then placed into six loose tubes. These tubes are sealed and surrounded with gel and heat-resistant wrapping to insulate them from the aluminum extruded tube covering them. In the design of an OPGW, it's better to keep the optical fibers in a complete aluminum tube at the center surrounded by ACSR (aluminum clad steel wires) or complete aluminum wires. This design keeps the fibers away from the effects of lightning. Since aluminum has lower resistance compared to steel, the aluminum tube surrounding the fibers will not heat up in case of a short circuit.

3. 2 Approach Cables

The cable used between the nearest tower and the communication room in the substation is of duct type and not armored. This choice is made to avoid the risk of high currents from lightning or short circuits reaching the communication room through the metal components of armored cables, potentially causing damage to the equipment.

3.3 Terminations of Fibers

The fibers in the communication room are connected to patch panels with a capacity of 144, allowing for future expansions. These patch panels are rack-mounted to minimize equipment size and are designed for easy expansion and accessibility. They are also dust-proof to withstand the common dust storms in Iraq. In 400 KV systems, the patch panels will have a capacity of 288. Considering the likelihood of future developments, OPGW should also be installed along the 400 KV lines.

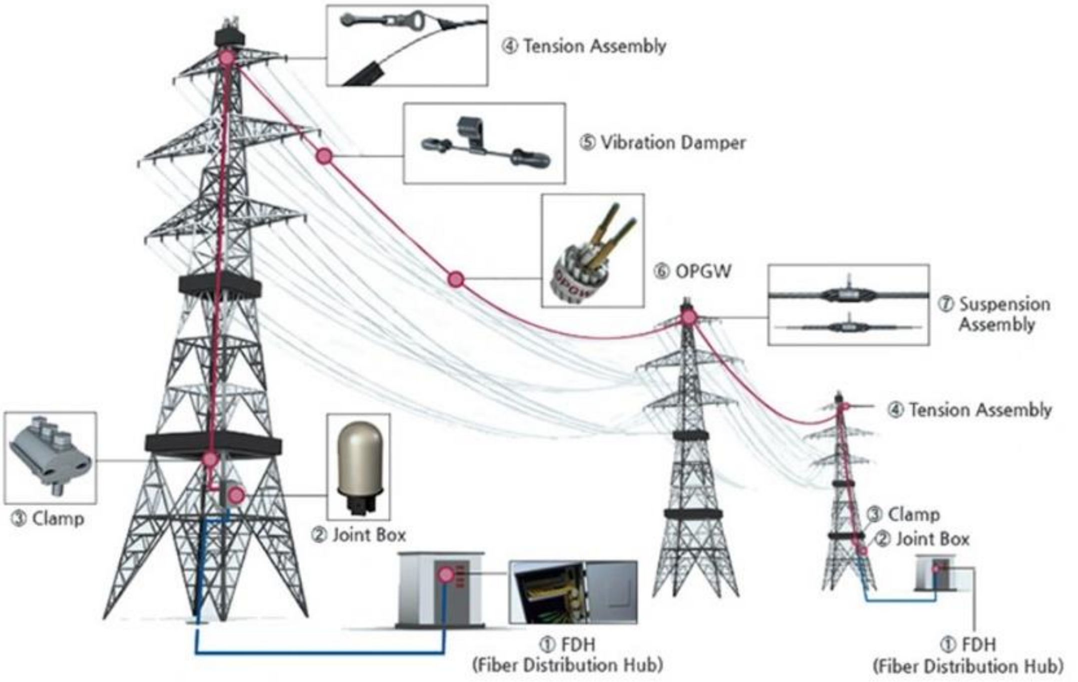
3.4 OPGW Testing

Using an optical time domain reflectometer (OTDR), we assess the attenuation of all fibers along the links and document splicing losses. Fiber attenuation typically ranges from 0.20 to 0.22 dB/km at 1550 nm, while splicing loss ranges from 0.03 to 0.05 dB. If attenuation exceeds these values, we investigate and identify loss issues at those specific locations.

Chromatic dispersion (CD) tests can be conducted using three methods: fiber Bragg grating (FBG), virtual image phased array (VIPA), and Gires-Tournois etalon (GTE). Such testing is essential for links spanning 50 km or longer.

Detailed test results show that a pair of fibers between Erbil and Sulaymaniyah, spliced entirely, while other pairs are spliced and reserved for future testing. These tests enable us to pinpoint the location of any damage in the event of a cut.

3. Design of Optical Networks and Solution



4.1 Optical Amplifiers

Optical amplifiers need to be deployed for links spanning 100 km [7]. The specifications for these amplifiers adhere to ITU-T G.662 "Generic Characteristic of Optical Amplifier Devices and of Subsystems" from July 2005. Specifically, pre-amplifier-type Erbium Doped Fiber Amplifier (EDFA) is implemented as per ITU-T G.663 item 5.2.

4.2 Wavelength Division Multiplexing

To meet the traffic requirements of the network, we aim to maximize the utilization of wavelengths in the fibers connecting substations. The wavelengths selected for this network fall within the C band (1530-1565 nm) due to minimal attenuation and nonlinear effects such as four-wave mixing in this band. We opt for an optical channel spacing of 100 GHz to mitigate the cross-phase modulation effect.

Stimulated Raman scattering is suppressed by restricting the input optical signal power to 1 mW. Although the total number of optical channels available is 32, we currently utilize only 16, reserving the remaining channels for future expansion. This approach ensures that any issues in the optical spectrum can be automatically improved in terms of signal-to-noise ratio, as outlined in [5]. It's crucial to carefully select the number of wavelengths, as exceeding 32 channels may lead to potential issues, as discussed in [7].

4.3 Bit-rate Assignments

The bit rate on W1 or W2 is set at 10 Gb/s to optimize the signal-to-noise ratio and channel quality. For the remaining channels, the bit rate is lower. However, our tests have confirmed that these optical channels are capable of transmitting signals at 10 Gb/s, in accordance with ITU-T G.697.

4.4 Ethernet Switching, MPLS and ROADM

MPLS (multi-protocol label switching) is employed to tightly integrate Layer 2 Ethernet switches with IP routers at Layer 3, enabling Ethernet switches to function as extensions of routers at Layer 3. This integration enhances control and integration of the entire IP network across both layers [7]. MPLS utilizes shorter labels (32 bits) compared to the 320-bit header of IPv6, making it well-suited for WDM. Its ample destination address space, advanced class of services, and sufficient bits in the time-to-live field render MPLS ideal for networks with a large number of nodes (up to 256), a figure close to the total number of substations in our optical network. Additionally, MPLS accommodates variable-length packets and facilitates stacking of several labels (last-in-first-out) before transmitting data flows from the first edge router, crucial for rerouting scenarios. Moreover, MPLS establishes virtual paths (known as label-switched paths or LSPs) between edge routers and reserves specific wavelengths for transmission.

MPLS supports transmission on different wavelengths by using either resource reservation protocol (RSVP) or label distribution protocol (LDP). As MPLS does not operate at the physical layer, so in case of physical layer failure, it re-routs LSPs. The design is also based on reconfigurable optical add multiplexing (ROADM) for the following advantage:

- Low insertion loss which increases OSNR
- Flat and sharp filter functions that enable up to 24 nodes to be in cascade operation.
- Flexible channel plan, which means that the 100 GHz channel spacing can be changed to 50 GHz in the future.
- Integrated optical channel monitoring that can track the wavelengths in the system with feedback information including OSNR and so on.

The wavelength selective switch (WSS) module and associated software can select individual wavelengths from 16 channels (32 in the future) from the input fiber and switch them to any output fiber. It is preferred to use digital light processing switches or liquid crystal on silicon technology, since with this technology, routing and wavelength dropping mentioned above would be possible.

4.5 Impairment and Light Path Routing

Within fiber-optic networks, impairments can be categorized into two types: linear and nonlinear. Linear impairments arise from factors such as amplified spontaneous emission (ASE), chromatic dispersion (CD), cross talk, filter concatenation (FC), and polarization mode dispersion (PMD). Nonlinear impairments, on the other hand, can be further classified into two categories:1- stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS).

2- self-phase modulation, cross-phase modulation (XPM) and four-wave mixing (FWM) [7]. To monitor above impairment, we assign an optical wavelength channel as monitoring channel. In case of any problem, this channel will feedback to the network control plan and give alert to the maintenance centers in Erbil and Sulaymaniyah. The system is based on routing and wavelength assignment (RWA) algorithm for light path routing and takes physical characteristics into account for the light paths selections. This means that the system utilizes impairment-aware algorithm (IA-RWA). To improve OSNR, we apply forward error correction (FEC) to make sure that bit-error-rate is less than 10-13.

4.6 Circuit-breaker Tripping

All circuit breakers on 132 KV lines are linked via optical fibers operating at E1 speed. Previous power line carrier (PLC) facilities are kept on standby. Recognizing the critical nature of this requirement, a dedicated pair of fibers is allocated exclusively for this function.

5. Conclusion

This article delves into the design of an optical network aimed at optimizing the utilization of 132 KV power transmission line infrastructures spanning from Erbil to Sulaymaniyah. The proposed optical network is engineered to meet the current demands for high-speed and reliable data, video, and voice communications from various sources including existing equipment, offices, operators, as well as maintenance engineers and technicians.

The design also considers future expansions, encompassing the integration of additional 132 KV and 400 KV substations into the network framework. To facilitate these expansions, surplus optical fibers within the Optical Ground Wire (OPGW) are deliberately reserved. These fibers will be instrumental in extending connectivity to all towns traversed or located adjacent to the network route. Consequently, residents of these towns will benefit from enhanced communication services once the planned expansions are realized.

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8. Author Biographies

Hemin Mustafa Ali (hemin.mustafa@gmail.com) earned his B.Sc. in Electrical and Communication Engineering from Salahaddin University in Erbil in 1998. From 2000 to 2003, he served as a Power Line Survey Supervisor for the UNOPS/ Power Line Survey in the Kurdistan Region of Iraq (KRG). Following this, he held the position of Head of Project Management Office (PMO) at Fanoos Telecom from 2005 to 2018. He later transitioned to the role of Program Manager in the PMO at Asiacell, where he served from 2019 to 2024.

Throughout his career, Hemin demonstrated exceptional proficiency and leadership. He successfully led the design and implementation of two significant Fiber Optic (FO) Network projects, one in Sulaymaniyah in 2005 and another in Kirkuk in 2012. Notably, he spearheaded a project facilitating the backbone connection between Sulaymaniyah and Kirkuk, making significant contributions to both towns in the KRG region, particularly in 2012.