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A Novel On-line Inspection System for Transmission Lines Using Optical Ground Wires

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Abstract. In order to obtain the desired visible images, the infrared images and the meteorological data for the inspection, a novel on-line inspection system for transmission lines is designed and proposed in this paper. The system consists of tower terminal units, Ethernet passive optical networks and master stations. Due to the huge monitoring data sampled by the tower terminal units at each tower, Ethernet passive optical networks are used to transmit the monitoring data in real-time. The fibers in the optical fiber composite overhead ground wires are used as the trunk fibers in the communication systems. They extend from the optical line terminal to the passive optical splitters located in the splice trays at each tower. Then the optical drop fibers are used to connect the tower terminal units and the splitters. A single-trunk-fiber network scheme, multiple-trunk-fiber network scheme and cascaded-OLT network scheme are proposed for the communication systems. The effectiveness and practicability of the proposed inspection system were verified by simulation results and the field data.

Keywords: EPON, inspection, OPGW, transmission line

Sistem za sproten nadzor vodnikov na daljnovodih z uporabo optičnega omrežja

V članku je predstavljen komunikacijski sistem za sproten nadzor vodnikov na daljnovodih. Sistem sestoji iz terminalne enote, optičnega omrežja ethernet in nadzorne postaje. Zaradi velike količine podatkov, katere zajemamo na vsakem daljnovodnem stolpu, smo za prenos podatkov v resničnem času uporabili omrežje ethernet. Podatki se po zajemu prenesejo do terminalne enote, kjer se izvede predobdelava zajetih podatkov, nato pa se prenesejo prek optičnega omrežja v nadzorno postajo. V prispevku smo predstavili tehnike za prenos velikih količin podatkov po optičnem komunikacijskem sistemu. Učinkovitost in uporabnost predlaganega pristopa smo preverili s simulacijami in testi v resničnem okolju.

1 INTRODUCTION

With the development of the power systems, the total length and coverage area of the high-voltage transmission lines has increased significantly. For the transmission lines and their attaching equipments to work safely, inspections are usually required.

The main inspection method is the manual inspection on schedule. Its disadvantages are high working intensity and high danger. Meanwhile, the manual inspection will be very hard to perform in a complicated geographical environment, such as mountain areas and aboriginal forests, or in severe weather conditions.

Recently, the helicopter and robot inspections for transmission lines have been presented and used in routine inspections [1-3]. But it is difficult for the helicopters to inspect in a complicated geographical environment or severe weather. More researches are needed to make the robot inspections practical, such as obstacle crossing and obstacle recognition. Meanwhile, the routine inspections cannot monitor the equipments in real-time and may cause overwork or absentation. So a novel inspection method is urgently needed to replace the routine manual inspections.

In order to monitor the equipment in real-time, the condition monitoring systems have been introduced into the electric power systems, including electric magnitudes monitoring [4], mechanical magnitudes monitoring [5], environmental monitoring, etc [6]. These systems are generally focused on one particular aspect and cannot obtain the overall operating parameters of transmission lines. Meanwhile, the general packet radio service (GPRS) or the code division multiple access (CDMA) are usually used as the communication systems in these monitoring systems, so the desired visible and the infrared images sampled at each tower cannot be transmitted in real time. Because these systems cannot meet the inspection requirements, the utilization ratio of these systems is low.

To overcome these drawbacks, a novel on-line inspection system for transmission lines is designed and proposed in this paper. It consists of tower terminal

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units, optic-fiber communication systems and master stations. The tower terminal units are designed to obtain the desired data for inspections and are installed at each tower along the transmission lines. The optic-fiber communication systems are used to transmit the monitoring data, including the visible and the infrared images and meteorological data. Meanwhile, a practical fusion splicing technique of the optical fiber composite overhead ground wire (OPGW) is applied in the proposed on-line inspection system.

2 STRUCTURE OF THE PROPOSED ON-LINE INSPECTION SYSTEM

Fig. 1 shows the structure of the proposed on-line inspection system, including the tower terminal units, optic-fiber communication systems and master stations.

The tower terminal unit consists of measuring units, terminal-host unit, power unit and optical network unit (ONU). The measuring units are used to sample the desired visible and infrared images and the meteorological data for the inspection. The terminal-host unit is used to collect the monitoring data, preprocess the data, upload the data and receive the commands given by the master station to control the devices.

The appropriate structure of the inspection system should be selected according to the field situation. Fig. 2 shows a two-layer structure, which includes the tower terminal units and the master station. Fig. 3 shows a three-layer structure, which includes the tower terminal units, the vice-master stations and the master station.

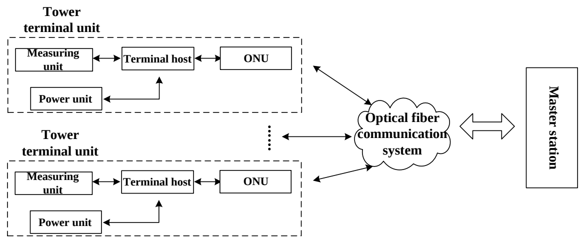

Figure 1. Structure of the proposed on-line inspection system

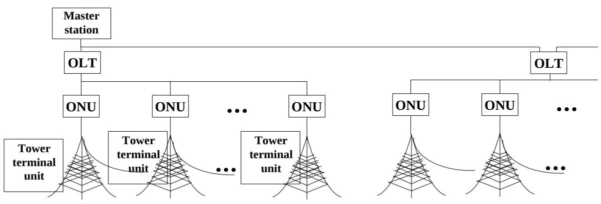

Figure 2. Two-layer structure of the inspection system

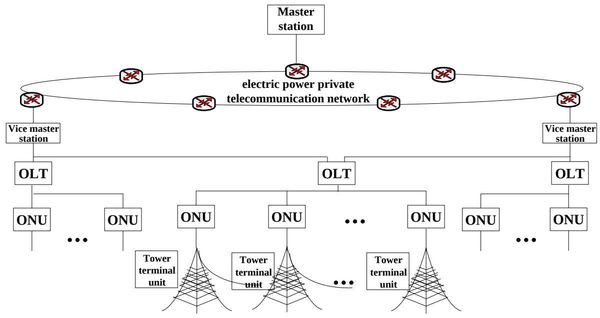

Figure 3. Three-layer structure of the inspection system

For the three-layer structure shown in Fig. 3, the monitoring data is transmitted to the vice-master stations firstly. Then the data reception, data storage, data analyses, data query and early warning are realized in the vice-master stations. After processing, the data is transmitted to the master station via electric power private telecommunication networks. The master station can query the storage data in the vice-master stations and analyze the accidents.

Table 1. The monitored objects in the transmission line inspections

Monitoring types	Monitored objects
Visible images monitoring	Transmission line corridor Tower fundations and protection facilities Tower and bracing wires Conductors and ground wires Insulators, insulator cross-arms and fittings Lightning protection facilities Vibration dampers and other subsidiary facilities
Infrared images monitoring	Composite insulators splices

The functions of the system depend on the inspection contents adopted by electric utilities, mainly including visible-image monitoring, infrared-image monitoring and microclimate monitoring. The monitored objects are listed in Table 1 according to the inspection contents.

3 OPTIC-FIBER COMMUNICATION SYSTEMS

3.1 *Communication mode*

The monitoring data sampled by the tower terminal units installed at each tower contains the visible and the infrared images, etc. So a high-bandwidth communication system should be designed to transmit the monitoring data in real-time.

The bandwidth required by one tower terminal unit is given in Table 2.

Table 2. The bandwidth required by one tower terminal unit

Monitoring types	Bandwidth/(bps)
Visible images monitoring	1.2M, two cameras
Infrared images monitoring	0.6M, one camera
microclimates monitoring	0.014M

Table 2 shows that the visible and the infrared images dominate the monitoring data. The bandwidth required by one tower terminal unit is about 2M bps.

The communication modes used in the electric power systems have Ethernet passive optical networks (EPONs), industrial Ethernets, GPRS/CDMA and wireless communication mode. In this paper, EPONs are chosen to transmit the huge data because of their low-cost point-to-multipoint optical infrastructure with low-cost high-bandwidth Ethernet.

3.2 Fusion-splicing technique of OPGW

The monitoring data sampled at each tower should be uploaded to the master station. Firstly, the sampled data is transmitted to the terminal-host unit. After preprocessing, the data is transmitted to the optical network units (ONU) installed in the tower terminal unit. Then ONU is connected to the passive optical splitter (POS) through the drop fiber.

The splices are carried out at each tower as shown in Fig. 4.

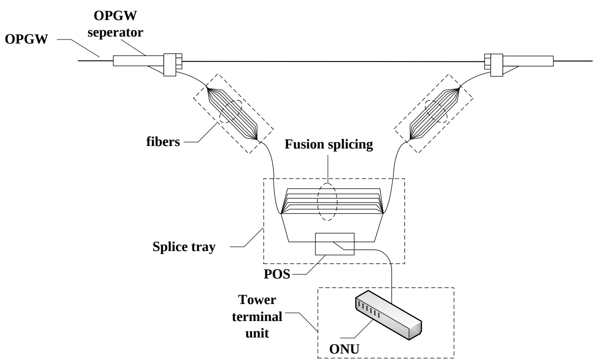

Figure 4. Fusion splicing of OPGW

Based on the fusion splicing technique of OPGW, the monitoring data can be transmitted to EPONs at each tower.

3.3 Network schemes for EPON

EPON is a passive optical network (PON) that carries all data encapsulated in THE Ethernet frames. All transmissions in PON are performed between an optical line terminal (OLT) and ONUs. In the proposed inspection system, OLT resides in the electric substation connecting the optical access network to the electric-power private telecommunication networks. ONU is located in the tower terminal unit installed at each tower.

An appropriate network scheme for EPON should be designed based on the transmission route and the idle fibers in OPGW. The designed schemes should guarantee that the optical total loss between OLT and each ONU is less than the optical power budget shown in (1).

$$P = \sum X_i + \sum H_i + \sum R_i + \sum F_i + G \le P_T \quad (1)$$

where, P represents the optical total loss between OLT and ONU. P_T is the optical power budget determined according to the fiber optic communications equipment. X_i is the transmission loss of the optical fiber in the i^{th} section. H_i is the loss of the optical fiber connectors in the i^{th} section. R_i is the splitting loss in the i^{th} section. F_i is the insertion loss of the POS in the i^{th} section. And G represents the optical power margin loss.

3.3.1 Single-trunk- fiber network scheme

As shown in Fig. 5, only a single fiber in the OPGW is used to transmit the monitoring data in the single-trunk-fiber network scheme. In this scheme, cascaded optical splitters are used and the loss of the optical power can be calculated by

$$P_{zn} = \sum_{i=1}^{n} X_i + \sum_{i=1}^{2} H_i + \sum_{i=1}^{2n} R_i + (\sum_{i=1}^{n-1} F_{gi} + F_{zn}) + G \quad (2)$$

$$P_{gn} = \sum_{i=1}^{n} X_i + \sum_{i=1}^{1} H_i + \sum_{i=1}^{2n+1} R_i + \sum_{i=1}^{n} F_{gi} + G \quad (3)$$

where, P_zn represents the optical power loss between OLT and ONU installed at the n^{th} tower. P_gn represents the optical power loss in the trunk fiber between OLT and the n^{th} tower. $F_{g\text{i}}$ is the insertion loss of POS along the trunk fiber at the n^{th} tower. F_zi is the insertion loss of POS along the branch fiber at the n^{th} tower.

The splitting ratios of the splitters should be chosen so as to guarantee that the network can provide as many ONUs as possible to access. Then the following splitting ratios should be chosen in the sequence of 95:5, 90:10, 80:20, etc.

3.3.2 Multiple-trunk- fiber network scheme

As shown in Fig. 6, the multiple-trunk-fiber scheme uses a multiple trunk fiber in OPGW to transmit the data. Firstly, ONUs access the first trunk fiber. When the actual loss between OLT and the last ONU is larger than the optical power budget, ONUs stop accessing the first trunk fiber and access the second fiber, and so on.

3.3.3 Cascaded-OLT network scheme

As shown in Fig. 7, two fibers are used and OLTs are installed along the transmission lines. This scheme can be used in the inspection system for the ultra long transmission lines.

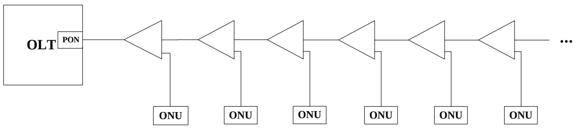

Figure 5. Single-trunk- fiber network scheme

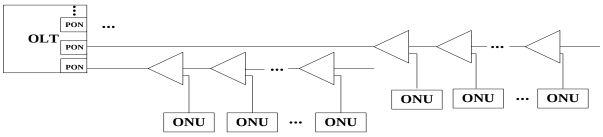

Figure 6. Multiple-trunk- fiber network scheme

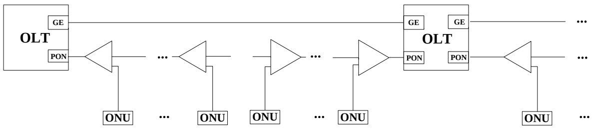

Figure 7. Cascaded-OLT network scheme

4 CASE STUDY

In the case study: 1) the optical power budget is set of 30 dB; 2) the tranmission loss of the fiber is set of 0.35 dB/km when the wavelength is 1310 nm; 3) the loss of the active optic-fiber connector is set of 0.5 dB per connector; 4) the splitting loss is set of 0.1 dB per joint; 5) the POS insertion loss is given in Table 3; 6) the optical power margin is given in Table 4.; 7) the tower span is set of 300 m.

For the single-trunk-fiber network scheme taken as an example, the calculation results of the optical power along the network are given in Table 5. Namely, twenty-four tower terminal units can access EPON.

Table 3. The insertion loss of the passive optical splitter

Splitting Ratio	The insertion loss/(dB)	
	Output port along the trunk	Output port along the branch
95:5	0.45	15.2
90:10	0.6	11.3
80:20	1.2	7.9
70:30	1.9	6.0
60:40	2.7	4.7
50:50	3.6	3.6

Table 4. The optical power margin

Distance from OLT to ONU/(km)	Typical value/(dB)
<5	1
<10	2
>10	3

Table 5. Calculation results of the optical power along the single-trunk-fiber network shown in Fig. 5

Tower number	The loss from OLT to ONU at the i^{th} tower/(dB)	The loss along the trunk from OLT to the i^{th} tower/(dB)	Splitting ratio at the i^{th} tower
1	17.505	2.355	95:5
2	18.260	3.110	95:5
3	19.015	3.865	95:5
4	19.770	4.620	95:5
5	20.525	5.375	95:5
6	21.280	6.130	95:5
7	22.035	6.885	95:5
8	22.790	7.640	95:5
9	23.545	8.395	95:5
10	24.300	9.150	95:5
11	25.055	9.905	95:5
12	25.810	10.660	95:5
13	26.565	11.415	95:5
14	27.320	12.170	95:5
15	28.075	12.925	95:5
16	28.830	13.680	95:5
17	26.685	15.585	90:10
18	27.590	16.490	90:10
19	28.495	17.395	90:10
20	29.400	18.300	90:10
21	26.905	19.805	80:20
22	28.410	21.310	80:20
23	29.915	22.815	80:20
24	29.520	25.020	70:30
25	29.325	28.925	50:50

For the multiple-trunk-fiber network scheme, the analyses show that: 1) the tower terminal units from the 1th to the 25th can access the first trunk fiber; 2) the units from the 26th to the 36th can access the second trunk fiber; 3) the units from the 37th to the 41th can access the third trunk fiber; 4) the units from the 42th to 44th can access the fourth trunk fiber.

5 FIELD DATA

Based on the proposed scheme, an experimental on-line inspection system for the transmission lines was developed and tested in the field, including two tower terminal units, EPON and one master station.


Figure 8. Developed tower terminal unit installed at the tower

Figure 9. Developed splice tray installed in the field

The tower terminal unit developed for the inspection system is shown in Fig. 8. It is designed in compliance with the tower structure. The developed splice tray installed in the field is shown in Fig. 9.

A typical visible image of the insulator obtained from the master station is shown in Fig. 10. A typical infrared image of the insulator is shown in Fig. 11. A user interface for video inspection/monitoring in the master station is shown in Fig .12.

Figure 10. Typical visible image of the insulator obtained from the master station

The above analyses and field data prove that the optic-fiber communication systems can transmit huge amount of the monitoring data in real-time. Meanwhile, the field data shows that the proposed on-line inspection system for the transmission lines can work effectively.

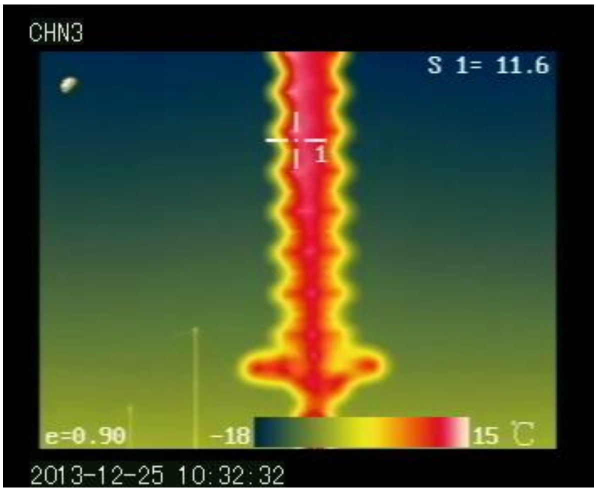

Figure 11. Typical infrared image of the insulator obtained from the master station

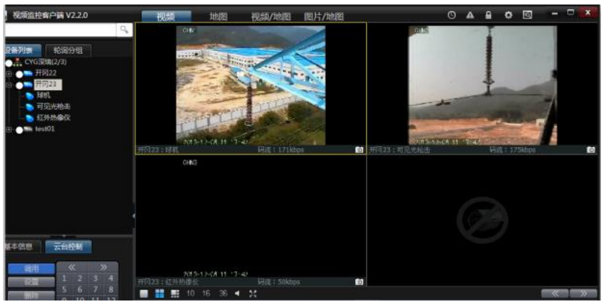

Figure 12. User interface for video inspection/monitoring in the master station

6 Conclusions

The proposed inspection system for transmission lines consists of tower terminal units installed at each tower, optic-fiber communication systems based on OPGWs and EPONs, and master station. It can obtain the desired visible and infrared images and meteorological data along the transmission lines to replace the routine manual inspections.

An early warning system based on the developed inspection system will be implemented and discussed in future papers.

Acknowledgements

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References

[1] Ian Golightly, Dewi Jones, “Corner detection and matching for visual tracking during power line inspection”, Image and Vision Computing, 21(9), pp. 827-840, 2003.

[2] Pouliot Nicolas. Montambault Serge, “Field-oriented developments for LineScout Technology and its deployment on large water crossing transmission lines”, Journal of Field Robotics, 29(1), pp.25-46, 2012

[3] Jaka Katrasnik, Franjo Pernus, Bostjan Likar, “A survey of mobile robots for distribution power line inspection”, IEEE Transactions on Power Delivery, 25(1), pp. 485-493, 2010.

[4] N. Bashir, H. Ahmad, “Odd harmonics and third to fifth harmonic ratios of leakage currents as diagnostic tools to study the ageing of glass insulators”, IEEE Transactions on Dielectrics and Electrical Insulation, 17(3), pp. 819-832, 2010.

[5] Zhitao Yan, Eric Savory, Zhengliang Li, et al, “Galloping of iced quad-conductors bundles based on curved beam theory”, Journal of Sound and Vibration, 333(6), pp. 1657-1670, 2014.

[6] R.K. Aggarwal, A.T. Johns, J.A.S.B. Jayasinghe, et al, “An overview of the condition monitoring of overhead lines”, Electric Power Systems Research, 53(1), pp. 15-22, 2000.

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