Research on application of tower sharing in overhead transmission line in China

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Abstract. As a social public infrastructure, overhead transmission lines were mainly used to transmit high load electrical energy and communication information. It was an important lifeline project, and had the characteristics of extensive spatial distribution, large number, and safe operation and so on. Transmission lines had a certain technical reserve and good feasibility in shared tower technology, in line with the communication and sensing industry of shared application and development. The results demonstrated that shared transmission line can support the application of different OPGW cables, acre station and micro base station for multiple vendors, and different sensing devices. It was showed very good economic benefit and social benefit in different shared application scenarios.

1. Introduction
With China’s national economy and electricity demand developing rapidly, China’s large-scale cross-regional power grid system is gradually improving, to meet green, low carbon and resource-conserving and environment-friendly social development [1]. The more reliable power grid was covered more extensive and comprehensive spatial distribution, and is highly similar with communication and sensing industry system in infrastructure. Transmission lines also had good technical reserves and research results in shared application and development field and were applied for related different industries. However, the sharing economy was first proposed in 1978 by Marcus Felson and Joel Spaeth (1978) [2], and has a good application results on power grid in Japan, the United States, the United Kingdom, India and other countries.

Recently, a new development stage of sharing and application of power basic resources has been spawned by the policy and market in China. 5G construction has entered the stage of rapid deployment [3], exploring the sharing of resources in the field of power and communication is helpful to realize the complementary advantages and to improve the efficiency of the utilization of state-owned assets. In July 2017, China Tower Co., Ltd began to carry out cooperation with Kunming Grid Company [4]. In the following year, State Grid and South Grid successively signed strategic cooperation agreements with China Tower Co., Ltd. In August 2019, multiple departments of the State Grid jointly issued the design and installation of shared tower technical guidelines [5]. In addition, related enterprises are studying the influence of base station equipment on lightning protection grounding and electromagnetic compatibility of the tower, and gradually propose the optimal shared tower technology scheme [6-8]. Therefore, this paper focuses on the application and technology of shared tower, including shared application basis, application scenarios and benefit analysis.
2. Shared tower application basis
Considering operation and intelligence level of overhead transmission line, it is seen as the most feasible and economic to research shared tower base on the existing communication technology and monitoring system, including OPGW cables, acre and micro base station, and sensing device. Therefore, this section focuses on the feasibility of sharing application technology between overhead transmission line and wired communication, wireless communication and different sensing equipment.

2.1. Shared requirements analysis

2.1.1. Analyze of shared application on wired communication. Wired communication is mainly used to solve the primary trunk network, secondary trunk network and local network information transmission [9]. With longer distance, larger capacity, high security and private communication line demand growing, constructing or hiring optical cable is the trend [10]. However, the exorbitant cost of laying special communication lines and maintenance, great workload and difficulty in construction prevent it from popularization. Moreover, the maintenance and service of overhead cable are not only expensive, but also are some problem with land acquisition, safely and easily to be destructed by external forces. Shared transmission tower between wired communication and power grid can solve above problem, because of the basically similar standards in these two fields. Both the established and newly built OPGW cables are able to support the two industries with technical and security. Besides, this technique cost less.

2.1.2. Wireless communication equipment sharing requirements analysis. With the development of 4G/5G technology, communication enterprises and tower companies have brought new challenges. The construction costs of 4G/5G base stations continue to rise as absence of ground resources, and maintenance and service are also expensive. Considering construction position coincides between the communication tower and transmission tower, installed 5G base station on transmission tower has low impact on structure, because of the light weight of wireless communication equipment. It is only necessary to focus on local optimization or local reinforcement for special structures or relatively weak structures. Therefore, taking transmission tower as the carrier of 4G/5G wireless communication base station, it will be feasible, necessary and economical to realize the shared application.

2.1.3. Sharing requirement analysis of sensing devices. Meteorology, ecology, fire, earthquake, navigation and positioning and other kinds of public perception system all need to build supporting structure, power supply and communication facilities [11]. All of this are not only expensive, but also cause the waste of social resources and the ground resources. On the other hand, transmission lines were widely distributed and quantity in the past, and tower could be leased to other industries [12, 13]. Using transmission tower as supporting structure to build sensing devices, it will reduce the land waste and construction cost. Sensing devices can be placed on electric towers easily because of its light weight and small size.

To sum up, it is very necessary and economical to rationally use or rent the communication optical cable and tower of transmission line as the supporter of wired, wireless communication and sensing equipment.

2.2. Structural safety analysis
In China, power grid, communication and sensing engineering adopted the probability-based limit state design method, which expression is standard value of load, material properties, and geometrical parameter, and various component coefficients [12, 14]. though the specification of transmission tower, communication tower and sensors are different, it will not effect on shared tower application, including design method, safety grade, seismic checking, material selection, and so on. The results support the following conclusions: firstly, the safety classes of transmission tower structure are between class 1 and class 2. But the communication tower and sensing support structure are generally below to class 2 [9, 15, 16]. Secondly, the recurrence interval of transmission tower is between 30years and 100years, and
their basic wind speed are between 23.5 m/s and 27 m/s. Compare with these values of communication tower, the recurrence interval and the basic wind speed are 50 years and 23.66 m/s, respectively [17, 18]. Thirdly transmission tower deflections requirement is calculated by load combination (ice-free, wind speed of 5 m/s and annual average temperature), but communication tower deflections requirement is no more than 1/2 half power Angle of microwave antenna. In the end, the maximum slenderness ratio of main leg, compression member, redundant bracing, and tension member of transmission tower, are 150, 200, 250 and 400, respectively. The communication tower maximum slenderness ratio of main leg, horizontal and oblique member, redundant bracing, and tension member are 150, 180, 200, and 350, respectively [9, 17].

Although there are several differences between transmission tower and communication tower, including recurrence interval, displacement limit value and slenderness ratio, etc., it is not significant considering span, structural style, material redundancy and checking computations. However, a complete calculation and check is necessary to be finished for practical engineering. In addition, in view of the existing sensing equipment are far less than the weight of communication base stations, transmission towers are also used to be sensing support structure, and meet layout requirements.

2.3. Electrical verify analysis

Considering live wire and tower grounded, the ground equipment generally needs to use horizontal laying with ground pole and ground line which are made by galvanized round steel. Reduction module or resistance reductions are used for high soil resistivity [19, 20]. However, the lightning rod of hot dip galvanized flat steel is used for lightning protection in communication basic station in communication and sensing field. Antenna, machine room and feeder also should be within the scope of protection. If the electrical connection of the metal components is confirmed to be reliable, no special lead wire will be set. In the other hands, the radio interference of high-voltage transmission lines is far below the working frequency band of GSM communication and the working frequency band of most sensing equipment, which means the transmission line do not affect work of GSM base station and sensing equipment [21]. Whereas, considering line conductor shelter and secondary radiation influence, the radiation impact of the public is not clear, which lack of engineering case study and the related test. But the factor will not affect the use of share transmission tower by optimization layout and equipment improvement [22].

Therefore, if the electrical connection of the metal components of transmission poles and towers is reliable, the lightning protection of the communication antenna will not be set up with download. The total length of the grounding of transmission poles and towers should not be less than 50m. Although the electromagnetic influence between transmission lines and communication equipment or sensing equipment can be temporarily ignored, it should be attention to the electromagnetic environment in the actual project, especially to the operation and maintenance work, and passing through the area in front of the antenna radiation port should be forbidden [23].

3. Shared application scenarios

As a social public infrastructure, overhead transmission lines can share applications with wired communication, wireless communication and different sensing devices. Base on transmission line universal design of state grid corporation of China, and the communication and sensing industry requirement, the specific sharing scenarios for each voltage level are shown in Table 1.

The Table 1 shows the specific sharing scenarios and typical layout height for each voltage level tower, which is mainly used for promotion reference. The actual overhead transmission line should be analyzed by structural safety and electrical verify, and satisfy demand for the communication or sensing industry requirement. The overhead transmission line tower needs to meet electric power engineering, communication and sensing industry standard, and communication antenna and sensing device load also need be analyzed. Because basic wind speed, ice thickness and the factor of wind pressure in high attitude could not be ignored, this paper provides a simplified wind load and ice thickness formula of
communication antenna or sensing device. The wind load of communication antenna or sensing device is calculated using the formula below:

\[ W_s = \beta_z \cdot \mu_s \cdot \omega_o \cdot \mu_z \cdot A_s \quad (1) \]

\( W_s \): the standard factor of wind load. The unit of the factor is kN;
\( \beta_z \): the wind vibration factor in height of Z that the suggested value should not be lower than 1.6.
\( \mu_s \): the shape factor of wind load which selected by Table 2.
\( \mu_z \): the height vibration factor of wind pressure,
\( \omega_o \): the basic wind pressure that is calculated by basic wind speed. The unit of the factor is kN/m².
\( A_s \): the wind area of communication antenna or sensing device. The unit of the factor is m².

### Table 1. The specific sharing scenarios for each voltage level.

| Scheme          | Direction                        | 10kV | 35kV | 66/110kV | 220kV and above |
|-----------------|----------------------------------|------|------|---------|-----------------|
| Wire communication | OPGW with 24/36/48 cores        | ●    | ●    | ●       | ●               |
|                 | OPGW with 72/96 cores           | ●    | ●    | ●       | ●               |
|                 | OPGW with 144 cores             | ●    | ●    | ●       | ●               |
| Wireless communication | Micro station (Top of tower) | ●    | ●    | ●       | ●               |
|                 | Micro station (Tower body)      | ●    | ●    | ●       | ●               |
|                 | 3 macro station (Tower body)    | ●    | ●    | ●       | ●               |
|                 | 9 macro station (Tower body)    | ●    | ●    | ●       | ●               |
|                 | 3 macro station (Top of tower)  | ●    | ●    | ●       | ●               |
|                 | 9 macro station (Top of tower)  | ●    | ●    | ●       | ●               |
| Sensing filed     | Monitor                         | ●    | ●    | ●       | ●               |
|                 | Meteorological observation      | ●    | ●    | ●       | ●               |
|                 | Fire protection                 | ●    | ●    | ●       | ●               |
|                 | Geological hazard               | ●    | ●    | ●       | ●               |

● Applicable scheme of shared application

### Table 2. The shape factor of wind load of communication antenna.

| Shapes          | Depth-width ratio is less than or equal to 7 | Depth-width ratio is greater than 25 |
|-----------------|---------------------------------------------|-------------------------------------|
| Wire communication | 0.8                                                       | 1.3 |

\( a \): Depth-width ratio is the ratio between the height and the diameter of antenna on vertical direction of wind.

\( b \): The factor could be selected by method of interpolation.

Besides, the ice load of communication antenna or sensing device should meet the requirement below:
The ice load of circular section member per unit length is calculated using the formula below:

\[ q_i = \pi \cdot b \cdot a_1 \cdot a_2 \cdot (d + b \cdot a_1 \cdot a_2) \cdot 10^{-6} \quad (2) \]

\( q_i \): the ice load per unit length. The unit of the factor is kN/m.
\( B \): the ice thickness. The unit of the factor is mm;
\( d \): the circular section diameter. The unit of the factor is mm;
\( a_1 \): the correction factor of ice thickness which is connected with diameter of sections and using by Table 3;
\( a_2 \): the height variation factor of ice thickness which could be selected by Table 4.
\( \gamma \): the ice thickness which is 9.0 kN/m³ generally.
Table 3. Correction factor of ice thickness which is connected with diameter of sections $\alpha_1$.

| Diameter (mm) | 5   | 10  | 20  | 30  | 40  | 50  | 60  | 70  |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|
| $\alpha_1$   | 1.1 | 1.0 | 0.9 | 0.8 | 0.75| 0.7 | 0.63| 0.6 |

Table 4. Height variation factor of ice thickness.

| Height from earth (m) | 10 | 50 | 100 | 150 | 200 | 250 | 300 | $\geq$350 |
|-----------------------|----|----|-----|-----|-----|-----|-----|-----------|
| $\alpha_2$            | 1  | 1.6| 2   | 2.2 | 2.4 | 2.6 | 2.7 | 2.8       |

The ice load of non-circular section member per unit length is calculated using the formula below:

$$q_a = 0.6b\alpha_2\gamma \times 10^{-3}$$  \hfill (3)

$q_a$ stands for ice load per unit area, kN/m².

3.1. Wired communication sharing

The typical scenario for transmission line shared with wire communication has showed in Table 1. The 110kV or above line, which located between cities, can be used for shared wire communication. The two-ground line on transmission towers should be expanded by OPGW with 48~144 cores. The capacity of communication equipment in the stations can be expanded accordingly. Meanwhile, the OPGW and the corresponding equipment can be used for the communication industry. The wire communication shared transmission tower is shown in the Figure 1. The shared application for wire communication will share the double OPGW and the two-end substation [10]. In this case, optical terminal equipment is placed in the substation. On the other hand, it will share the segmented part of a transmission line and the optical terminal equipment is built by the sharing party.

3.2. Wireless communication sharing

In the scenario of overhead transmission lines sharing wireless communication, there are mainly two kinds of positions for installing communication base station, including tower body and the top or head of the tower, and the machine room and external distribution line are provided. Different suppliers of antenna can be installed with the same layer, or rise the height of tower. The installation equipment of tower head is not affected by space, but the tower structure has to be check, and lightning rod should be added. Otherwise, the maintainer should be trained strengthened. In the Figure 2, it is shared application used in 220kV line. Base station equipment is placed on tower body 25 meter above the ground, including 3 antennas and 3 BBU+RRU on tower. The three operators in China, which are China mobile, China Telecom, China Unicom, will take up a platform respectively. As the antenna feeder, the copper core cable diameter is no less than 16 mm². The antenna feeder enters the machine room, which is placed in the range of tower root, through tower body. Besides, the wireless equipment needs external power supply.

3.3. Sensing devices sharing

Shared sensing scenario is the deep integration of overhead transmission and various public perception devices such as ecology, meteorology, firefighting, geological disaster, positioning and navigation. Figure 3 is an example for shared application with sensing devices in the overhead transmission line. The equipment for observe the wind speed, wind direction, temperature difference and air quality was installed on tower 15~30 meter above the ground, and hydrology, soil, animal and plant and other ecological monitoring and disaster monitoring equipment were installed in 5m or underground. In addition, the multifunction monitor, which including fire protection, ecological, ground disaster, positioning, navigation functions, temperature, humidity, galloping, ice accretion, and pollution functions, was placed at 20 meters above the ground. All of the devices are connected with the tower body, which mainly integrates monitoring, data acquisition, data storage, image and video, data
broadcast, communication and power supply functions, etc. The power supply system and communication module can also be set in the special platform of 5 ~ 10m height of the tower [11, 24].

4. Sharing application benefits
The application of shared communication and sensing equipment in transmission lines can realize the sharing of resources, reduce social investment, and realize the common development of power grid and other related industries. There are considerable economic and social benefits.

4.1. Shared economic benefits
First of all, it is cheaper to rent transmission line compared with the independent construction of communication line and tower. Secondly, shared application can also solve compensation for land requisition, land clearing and maintenance. Thirdly, the economic benefits will be maximized while the communication room and supporting power supply facilities were placed nearby.

4.2. Shared social benefits
The shared application of communication and sensing fields in overhead transmission lines meet the requirement with the national development concept of green, environmental protection and low carbon. At the same time, it will provide more widely, accurately and timely data from communication, meteorological, environmental monitoring to government departments. In this case, the 5G technology can be widely used, and improve national disaster prevention and mitigation capabilities.

5. Conclusions
A great economy and social benefits are realized in shared application. Because China's power grid system is very well developed and extensive spatial distribution, it became possible for shared communication and sensing equipment based on overhead transmission line. The results support the following conclusions:

Firstly, shared application will absolutely meet the requirement of large-scale construction of communication base station and lines. Meanwhile, a part of sensing equipment has proved running well for 10 years when were placed on transmission tower. Secondly, the OPGW cable with kinds of core numbers and base station of different suppliers can be applied to share in different overhead transmission lines, and almost all sensing devices are able to place on transmission tower. The tower structure check calculation reference Formulas (1) ~ (3) and the specific sharing scenarios were shown in Table 1. Finally, in order to improve the design of overhead transmission line sharing application, the research in some field are necessary, such as general design of 3D shared tower, power supply, distribution characteristics of electromagnetic field and lightning protection and grounding at present. In addition, the pricing model for renting power resource should be proposed and researched.
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