whole tower usually is difficult for the heavy-load carrying pylons due to the high cost, however, it can be accepted when the main structures still employ the steel but the cross arms adopt GFRP (Saboori and Khalili 2011). During the structural design in GFRP-steel composite pylons, the ice-resistant capacity induced by adopting GFRP cross arms (e.g., the jump height distance of wires and internal force of cross arm) should be attached great importance (Jones and Peabody 2006, Kollár et al. 2012).

Fig. 1 Ice disaster in transmission towers

Fig. 2 GFRP-steel composite transmission towers

Many researchers have carried out numerical modeling on ice-shedding response of traditional steel transmission tower-line coupling system. Fekr and McClure (1998) studied the dynamic response of a two-span transmission tower-line system under 21 ice-shedding conditions. McClure and Lapointe (2003) analyzed the transient response of electric wires under the impact loading (e.g., component damage and break line), and conducted a comparative study of the two-dimensional and three-dimensional tower-line coupling system. Kalman et al. (2007) simulated the dynamic response of single ground wire in the impulsive load caused by the mechanical de-icing; subsequently, the effects of different span distance and impulsive loads on ice-shedding were investigated for the establishment of failure criterion based on stressstrain relationship. Yang et al. (2010, 2014) studied the ice-shedding response by varying the spacing bar diameter, ice thickness, span distance and elevation difference, etc. Ji et al. (2015, 2016) calculated the adhesive and cohesive force of ice for suggesting a criterion of ice-shedding. Moreover, some scholars also performed relevant experimental research on the ice-shedding response of the traditional steel transmission tower-line coupling system (Kollár et al. 2010, Meng et al. 2011 and 2012). However, it should be noted that aforementioned numerical studies mainly aimed at the traditional steel tower-line system; besides, the relevant experimental research usually be limited to the scaled test model and can hardly to simulate the actual dynamic response caused by ice-shedding. Therefore, this paper performed numerical modeling on ice-shedding response of the new-type GFRP-steel composite transmission tower-line coupling system for providing the basic design references.

2. GFRP-STEEL COMPOSITE TRANSMISSION TOWER-LINE COUPLING SYSTEM

This section introduced the establishment and validation of the finite element model of the coupling system, including the GFRP-steel composite transmission tower, wires and insulator, different tower-line coupling system and the model validation.

2.1 GFRP-steel Composite Transmission Tower

A practical cat-head transmission tower (height=68.2 m) in China was taken as an example for ice-shedding analysis in ANSYS program. The origin in overall coordinate system of GFRP-steel composite tower was set at the center of the tower head; the z-axis orientation toward gravity was positive and the x-axis was perpendicular to the wires. The composite transmission tower was established in beam element method. The tower model was shown in Fig. 3 and the material properties were listed in Table 1.

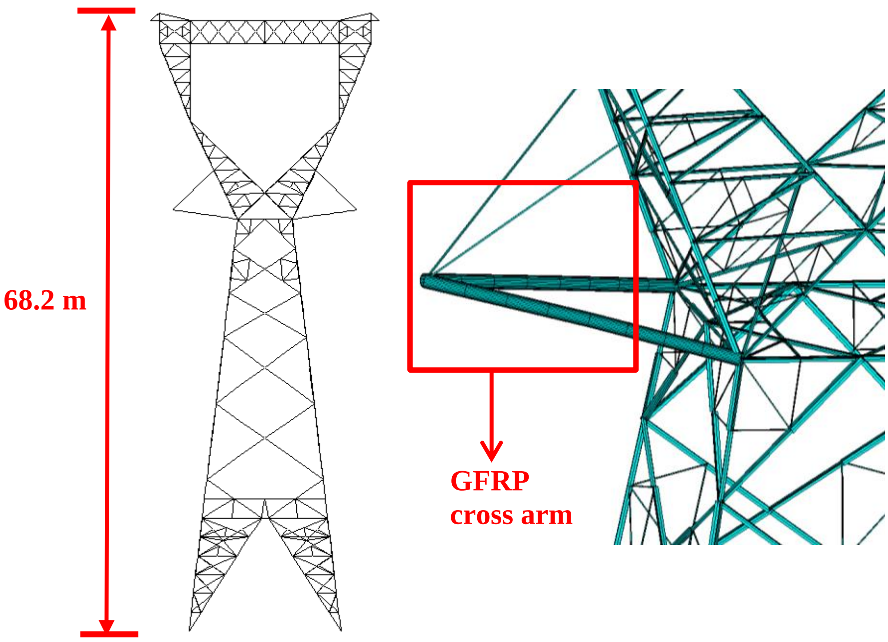

Fig. 3 Finite element model of GFRP-steel composite tower

Table 1 Basic material property

Component	Material	Density /kg/m^3	Poisson's ratio		Elastic modulus/GPa		Shear modulus/GPa	
Cross arm	GFRP	2000	PRXY	0.287	EX	43.15	GXY	16.5
			PRYZ	0.091	EY	14.32	GYZ	2.48
			PRXZ	0.287	EZ	14.32	GXZ	16.5
Main steel body	Q235～Q420	7850	0.3		206		/	

Note: The constitutive model of steel adopted elastic-perfectly plastic relationship.

2.2 Coupling System

In the GFRP-steel composite transmission tower-line coupling system, the wires could be simulated by the cable element based on the catenary equations (Yang et al. 2010). Therefore, the wires in coupling system can be modeled based on the actual parameters in Table 2, especially for the tension force and sag.

Table 2 Parameters of wires

Parameter	Conductor wire		Ground wire	
	Span: 400m	Span: 500m	Span: 400m	Span: 500m
Type	4×JL/LB1A-500/45		JLB20A-120	
Area/mm^2	531.68	531.68	121.21	121.21
Elastic Modulus/MPa	66000	66000	14720	14720
Poisson's ratio	0.3	0.3	0.3	0.3
Unit weight/ kg/m	1.6353	1.6353	0.81	0.81
Tension force / N	17651	17325	7140	6959
Sag/m	18.21	29.03	22.33	35.88

Based on the aforementioned finite element model of composite tower, the coupling system could be developed by assembling the wire model. In this paper, three different coupling systems were respectively established (Fig. 4, Fig. 5 and Fig. 6), moreover, the fixed constraints were applied at the ends of the wires and tower foots (Fig. 7). Moreover, the joint part between the tower and wires could be modeled by the simplified insulator link (Fig. 8), and the detailed parameters were shown in Table 3.