China Corner

Recent Progress in Electrical Insulation of Wind Generator in China

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1. Overall

1.1 Development and Forecast of Wind Power in China

Wind energy, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, and pro-duces no greenhouse gas emissions during operation. The abundant inland and offshore wind energy resources provide China with potential for large-capacity, in-grid wind farms. Large-scale wind farms are connected to the electric power transmission network; smaller facilities are used to provide electricity to isolated locations [1].

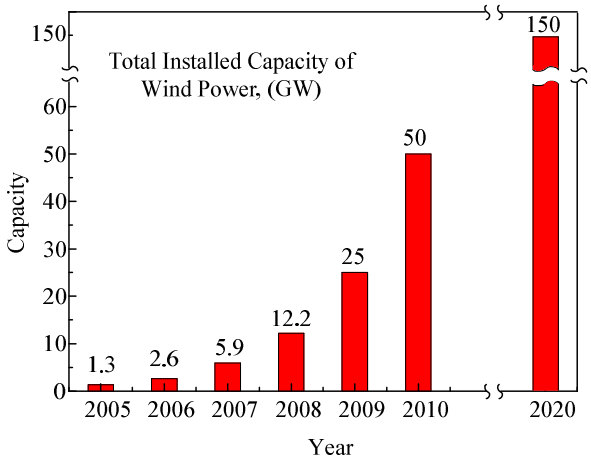

Fig. 1 Total installed capacity of wind power in China from 2005 to 2009, and the predicted total installed capacity in 2010 and 2020 are 30 GW and 150 GW, respectively.

As shown in Fig. 1, wind power in China develops very fast from 2005, and the total installed capacity has reached 25 GW in 2009. It is predicted that the total installed capacity will be 30 GW in 2010 and 150 GW in 2020, which would complete the plan that raise the total installed capacity of wind power to 30 GW, which is set by National Development and Reform Commission in "Medium and Long-Term Development Plan for Renewable Energy in China" [2-4].

Table 1. Energy Structure of China in 2009

Energy Category	New Installed Capacity of 2009 (GW)	Total Installed Capacity Until 2009 (GW)	Total Generating Capacity of 2009 (billion kWh)
Thermal Power	60.76	652.05	2986.7
Hydropower	19.89	196.79	512.7
Wind Power	8.97	16.13	26.9
Nuclear Power	--	9.08	70.0
Total	89.70	874.07	3596.5

The data in table 1 refer to the Grid-connected installed capacity. Although the wind power develops very fast, there is a big gap between the current status and the target that raise the share of renewable energy in total primary energy consumption to 15 percent in 2020.

1.2 Wind Power Demonstration Project

Shanghai Donghai Bridge offshore wind power demonstration project was completed on July 6, 2010, and started to supply clean energy to Shanghai city [5, 6].

As shown in Table 2, the wind farm established 34 homemade 3 MW wind turbines, with a total installed capacity of 102,000 kW, the annual power generation capacity of 267 GWh, which is the first time to install independent research and development of 3 MW offshore-type units that marks the high-power wind turbine equipment of China among the world's most advanced manufacturing.

Furthermore, the East China Sea Bridge wind farm Phase II (100,000 kilowatts level) preliminary work has been approved by the relevant departments.

Table 2. Relevant parameters of the East China Sea Bridge wind farm

Total number of wind turbine generators	34
Total Capacity (MW)	102
Electricity generation hours per year (h)	2624
Electricity provided to the grid per year (GWh)	267

1.3 Three National Research and Design (R&D) Centers of Wind Power

China's National Energy Administration has formally approved 38 energy R&D centers in the last two years, in which have 5 R&D centers on wind power that are National Energy Offshore Wind Power Technology and Equipment R&D Center, National Energy Large-scale wind power Grid Connected System R&D Center, National Energy Research and Development (experimental) Center of Wind Turbine Blades, National Energy Wind turbine R&D center, and National Energy R&D center of Wind Power Operations [7, 8].

These R&D centers are of great significance in establishing China's energy and technology support system, meeting national and strategic needs for innovative energy structure optimization and upgrading and satisfying market demand for energy technology and equipment.

2. Developments of Electrical Insulation Technology of Wind Generator

Wind turbines are used to tap the potential of wind energy, which is available in millions of MW. Reliability of wind turbine is critical to extract this maximum amount of energy from the wind. Considering the complex and diverse operating conditions in China, such as very low

or high temperatures, alternating hot and cold temperatures, high humidity, salt spray, dust, high altitude, low wind speed and coastal areas, we need to design and produce a broad range of wind generators which can be installed in diverse climates and work efficiently in operating conditions. These harsh environments require high reliable wind generators, which put forward very strict requirements for the insulation systems [9], such as the insulation of stator windings, collecting ring and brush unit, and cable. The strategic points of the insulation systems are able to work at the harsh environments.

The towers of the wind generators are very high, some of which are more than 100 m, and are usually the highest object in its area, so it is very easier for them to be stroke by the lighting. Therefore, much more attentions should be paid to the lighting stroke and overvoltage protection.

2.1 Stator Windings

The wind turbines operate at the special geographic environments, such as, Gobi, grassland, and seaside, which have special requirements on insulation system and materials. A lot of research and design have been done on this field.

Firstly, the wind turbine insulation system consisted of solvent-free polyesterimide impregnating resin, mica tape with polyester and molten polyimide lapped magnetic wire was studied and the results showed that the insulation system had lower dielectric dissipation factor (better than the excellence goods performance indicators), good salt spray resistance and high and low temperature insulation performance (reach the excellent level), high breakdown voltage (average voltage, 24.4 kV). It was said that the insulation system was one of the best insulation systems with excellent insulation properties [10-12].

Secondly, a kind of surface insulating coating with a base material of high molecular weight epoxy resin used in wind turbine generators was developed, which demonstrated that the coating exhibited better electrical insulation properties when certain high molecular weight epoxy resin was used as the base material. Its volume resistivity achieved 9. 6 $\times 10^{13}$ Ω·m, electric strength was 67 MV/ m and arc- resistance was 127 s. The salt spray resistance was improved to 1000 h when using mica powder and aluminum triphosphate as pigments and fillers, and the wear resistance could reach 0.037 g when choosing an elastic curing agent modified by polyether, which meant that the surface insulating coating reached the same level of international product [13].

Thirdly, a kind of heat temperature epoxy resin glass fiber cloth laminated sheet was manufactured, and it had excellent high thermal endurance, machine performance and electrical properties, which reached the same level of class H epoxy resin glass fiber laminated sheet that is manufactured by an Europe company [14].

2.2 Collecting Ring and Brush Unit

Insulation is the key technology of collecting ring and brush unit, which need the properties of high dielectric performance, low leakage current, good corona resistance at high voltage, stand high and low temperature, and enough mechanical strength and so forth according to the harsh operating environment of wind turbine generators [15-18].

However, the insulation materials of the original collecting ring and brush unit in the wind generators produced by Chinese factories are phenolic pressure plastic, epoxy fabric laminates, or film mica plate, and the fit between conducting rod and conducting ring is clearance fit, which have a lot of shortcomings, such as, partial discharges, even arcs in the contact gap that lead to the aging or breakdown of the insulation materials, toner scattered and deposited on the insulation among the phases, causing short circuit of wind generators.

Table 4. Comparisons of the original collecting ring and brush unit and the improved collecting ring and brush unit in China

	Original collecting ring and brush unit	Improved collecting ring and brush unit
Insulation structure	Clearance fit between conducting rod and conducting ring	Slip fit between conducting rod and conducting ring, adding insulation sleeve
Insulation material	Phenolic pressure plastic, epoxy fabric laminates, film mica plate	Composite insulation of mica tape and glass cloth

As shown in table 4, plenty of researches have been done to improve the performance of collecting ring and brush unit, for example, composite insulation of mica tape and glass cloth was used to increase the dielectric properties and reduce the costs, clearance fit was changed to slip fit by coated the relevant components with dielectric materials or added insulation sleeve inside the collecting ring. Therefore, the improved collecting ring and brush unit are suitable for high speed and long life wind generators and can be used in the harsh environment with high humidity, very high or low temperature and lighting, etc.

2.3 Power Cable

The original wind turbine generator power cables are composed of single hard thick copper wire and traditional rubber-like insulation and sheath, which have a good heat resisting property. As the diameter of the copper conductor is very large, it is difficult to bend and install the cable, and the mechanical and tearing strength of the traditional rubber-like materials are very low, so the insulation and sheath layer are easy to crack.

The improved cables adopt the soft brass wires or soft tinning brass wires with the diameter of 0.15~0.5 mm intertwisted with each other in the same direction as the conductors, and thermoplastic vulcanizate, silane cross-linking ethylene/propylene rubber, high tear resistant silicone rubber compounds, polyvinyl chloride as the insulation materials, and vulcanizate elastomer, PUR-elastomer compound, polyurethane as the sheath materials. Moreover, many of the improved cables add some new layers, such as strengthening cladding layer and flame retardant layer, to improve the performance that are anti radiation, stand abrasion, seawater corrosion

Table 5. Comparisons of the original cables and the improved cables in China

Components	Original Cable	Improved Cable
Conducting wire	Single hard thick copper wire	Many soft brass wires with the diameter of 0.15~0.5 mm intertwist with each other in the same direction
Insulation layer	Traditional rubber-like materials	Thermoplastic vulcanizate, silane cross-linking ethylene/propylene rubber, high tear resistant silicone rubber compounds, polyvinyl chloride
Sheath layer	Traditional rubber-like materials	Vulcanizate elastomer, PUR-elastomer compound, polyurethane
The others		Strengthening cladding layer, flame retardant layer

resistance, and so on. Besides the general properties of the power cables, such as good high/low temperature resistance, good oil resistant, good corrosion resistance, etc., the improved cables have better mechanical property than the original ones, and they are softer, which make them easier to bend, distort and install, shown in table 5 [19-22].

2.4 Lighting Stroke and Overvoltage Protection

With the increase of the capacity of wind turbines, towers are heightened to obtain more wind energy, which causes the increase of the lightning stroke risk. Wind turbines being repeatedly struck by lightning will increase generator stator insulation deterioration, eventually may cause insulation breakdown incidents [23-26].

Lightning surge on the stator windings of megawatt direct-driven wind turbine generators was analyzed with the surge arresters installed on the terminal of generator and two sides of transformer, which show that the coil-to-core voltage raise when lightning spread to the generators, the voltage distribution along the windings is non-uniform initially, and the highest voltage appears near the neutral. The surge arresters can effectively restrain the lightning overvoltage.

It is more difficult to protect the doubly fed induction wind generators from lighting stroke and overvoltage, for the doubly fed induction wind generators is easier inflected by the induced voltage from lighting stroke. Therefore, a new protection system was developed whose structure was that a surge arrestor and fuse grounded to the earth was connected in series with the stator, and a surge arrestor and fuse linked with a grounded gap arrestor was connected in series with rotor.

In conclusion, although we have made some progress on the technology of insulation in wind turbine generators, we should accelerate our pace to localize at least 70% of the wind turbine generators in the newly-built wind farms [2].

Reference

[1] http://en.wikipedia.org/wiki/Wind_power.

[2] National Development and Reform Commission. Medium and Long-term Development Plan. Sep., 2007.

[3] China Wind Power. Interim Report of Achievements. Jun., 2010, (in Chinese).

[4] The State Economic and Trade Commission Resource Conservation and Comprehensive Utilization. New Energy and Renewable Energy Development Plan Points from 2000 to 2015. Aug., 2000, (in Chinese).

[5] http://www.china.org.cn/environment/news/2009-04/17/content_ 17625802.htm

[6] http://english.peopledaily.com.cn/90001/6627411.html

[7] http://www.chinacsr.com/en/2010/01/11/6942-china-establishes-16-national-energy-rd-centers/

[8] http://www.ce.cn/cysc/ny/dl/201007/23/t20100723_20443786.shtml

[9] Huilin Xu. Discuss the Insulation System of MW Capacity Wind Power Generator.2009 Insulation Material and Technology Develop Conference of Insulation Material and Insulation Technology Professional Committee of China Electrotechnical Society , (in Chinese).

[10] Qibin Jiang, Qiangjun Li, Hongsheng Chen, *et al*. Research of Insulation Systems and Materials for Direct-drive Wind Turbine. 2009 Insulation Material and Technology Develop Conference of Insulation Material and Insulation Technology Professional Committee of China Electrotechnical Society, (in Chinese).

[11] Changzhi Xue, Hong sheng Chen, Yangjie, *et al*. TJ 13-3 polyester-imide Solventless Impregnating Resin and Application in Wind Turbines. Insulation Materials, 2010, 43(1), pp.34-36 , (in Chinese).

[12] Qiangjun Li, Qibin Jiang, Hongsheng Chen, *et al*. Research of Insulation System for Direct-drive Wind Turbine. Insulation Materials, 2009, 42(3), pp.10-13 , (in Chinese).

[13] Fanhui Zeng, Qibin Jiang, Xianhong Chen, et al. Surface Insulation Coating for Wind Turbine Generator. Insulation Materials, 2010, 43(2), pp.17-23 , (in Chinese).

[14] Daoming Luo. High Temperature Insulation Material of Wind Generator. 10th Academic Exchange Meeting of Insulation Material and Insulation Technology, Beijing, Sep., 2008, (in Chinese).

[15] Taili Wang. Compound Insulation Collecting Ring of Generator. CN200920064828.8, Jun, 2009, (in Chinese).

[16] Jianming Cao, Xinhua Cao, Haibing Yang. A Insulation Structure of Collecting ring and Brush Unit of Wind Generator. CN2008201571043, Dec., 2008, (in Chinese).

[17] Weiqiang Zhao. Collecting Ring of Small Type Wind Generator. CN200820050006.X, Jul., 2008, (in Chinese).

[18] Wanxi Chi, Jianmin Yang, Yangyu Jin, *et al*. A Collecting Ring of Wind Generator. CN200920116674.2, Mar., 2009, (in Chinese).

[19] Changqing Wu, Yinyu Su. Power Cable of Wind Generator. CN200820220011.0, Nov., 2008, (in Chinese).

[20] Qibin Wang. Dedicated Power Cable of Wind Generator. CN200920186389.8, Jul., 2009, (in Chinese).

[21] Peicai Yang. Wind Power Cable. CN200920042075.0, Apr., 2009, (in Chinese).

[22] Hekuai Wu, Renjun Gu, Houwu Zhu. A Kind of Wind Power Cable. CN200720045102.0, Aug., 2007, (in Chinese).

[23] Rong Liu, Xuezhong Liu, Ying Wang, et al. Simulation of Lighting Overvoltage Distribution on Stator Windings of Wind Turbine Generators. 2010ACED, accepted.

[24] Binsuo Li, Xuelin Jiang. Eumatic Active Lighting Arrester. CN200820064935.6, Aug., 2008, (in Chinese).

[25] Yuguo Zhu. Lighting Arrester of Wind Generators. CN200920028633.8, Jun., 2009, (in Chinese).

[26] Xiang Li. Lighting Stoke Protecting System of Wind Generators. CN200720061834.9, Dec., 2007, (in Chinese).

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