1 MVA HTS-2G Generator for Wind Turbines

K L Kovalev[1], V N Poltavets[1], R I Ilyasov[1], L G Verzhbitsky[2], S S Kozub[3]

[1] Moscow Aviation Institute (National Research University), Dept. 310, 4, Volokolamskoe Shosse, Moscow, 125993 Russia
[2] JSC "NIIEM", 11, Panfilov St., Istra, Moscow region, 143502, Russia
[3] Institute for High Energy Physics, 1, Nauki Sq., Protvino, Moscow region, 142281, Russia

E-mail: Ilyasov@mai.ru

Abstract. The calculation, design simulations and design performance of 1 MVA HTS-2G (second-generation high-temperature superconductor) Generator for Wind Turbines were done in 2013-2014 [1]. The results of manufacturing and testing of 1 MVA generator are presented in the article. HTS-2G field coils for the rotor were redesigned, fabricated and tested. The tests have shown critical current of the coils, 41-45 A (self field within the ferromagnetic core, T = 77 K), which corresponds to the current of short samples at self field. Application of the copper inner frame on the pole has improved internal cooling conditions of HTS coil windings and reduced the magnetic field in the area, thereby increased the critical current value. The original construction of the rotor with a rotating cryostat was developed, which decreases the thermal in-flow to the rotor. The stator of 1 MW HTS-2G generator has been manufactured. In order to improve the specific weight of the generator, the wave (harmonic drive) multiplier was used, which provides increasing RPM from 15 RPM up to 600 RPM. The total mass of the multiplier and generator is significantly smaller compared to traditional direct-drive wind turbines generators [2-7]. Parameters of the multiplier and generator were chosen based on the actual parameters of wind turbines, namely: 15 RPM, power is 1 MVA. The final test of the assembled synchronous generator with HTS-2G field coils for Wind Turbines with output power 1 MVA was completed during 2015.

1. Introduction

The main application of the developed HTS-2G generator is the usage as a generator for wind turbines. The application of superconducting materials allows one to reduce weight and dimensions of the wind turbine with the same output power, or to increase the nominal power while maintaining the weight.

The developed HTS-2G generator can operate in the motor mode as well. So it can be used as a drive for the transport system.

Using excitation windings of the second-generation, the high-temperature superconductor (HTS-2G) allows one to obtain high magnetic flux in the air-gap, to increase the current and the efficiency compared to the conventional synchronous wind turbine.

The progress of production of HTS-2G tapes during the last years has shown a steady growth of the critical current of the HTS tape in the presence of magnetic field allowed, and, therefore, has increased

power density of the wind turbine. Currently, the increase of power higher than 1 MVA is already possible by using a closed cycle cryogenic system with overcooled liquid nitrogen down to 65 K.

The inner diameter of the developed generator is 0.8 m. The active length of the stator is 0.4 m. The total weight of the generator is 4200 kg.

The previously developed high power generators (usually with low-temperature superconductors) possess rather low specific power at the order of 0.07 kg / kW and the efficiency, less than 95% [8]. Nominal specific power of the devoloped HTS-2G generator (without mass of multiplier) is 0.24 kg / kW, which for the synchronous generator with a nominal rotation speed of 600 min^{-1} is a good indicator.

2. The design of the HTS-2G generator
Parameters of the 1 MVA Synchronous HTS-2G Generator are shown in Table 1.

Table 1. Parameters of 1 MVA Synchronous HTS-2G generator

List of Parameters	units	value
Nominal Output Power	kVA	1000
Phase voltage	V	690
Nominal Speed	min^{-1}	600
Pole number	-	10
Nominal current	A	500
Inner diameter of the stator	mm	800
Active light	mm	400
Mass	kg	4200
Material of stator winding	-	Cu
Operating temperature of stator winding	K	300
Material of field coils	-	HTS-2G tape
Operating temperature of field coils	K	77
Nominal current in field coils (in 0.5 T field)	A	40
Number of turn per one pole	-	388
Operating Power factor	-	0.95 – 0.99
Full load efficiency (without the cryocooler)	%	97 – 98

The generator has 10 poles. Each pole consists of 3 double-pancake HTS coils with the total number of turns 388. HTS tape (AMSC – Amperium™, Type 8501 [9]) dimensions are 4.8×0.21 mm^2 without insulation. The real thickness of tapes, isolated by Kapton, based on the actual winding density, was 0.38 mm. The total length of HTS tape for field coils that has been used is about 5.2 km. The HTS coils are cooled with liquid nitrogen, which circulates through channels in the pole and wedges (see fig. 1 and 2).
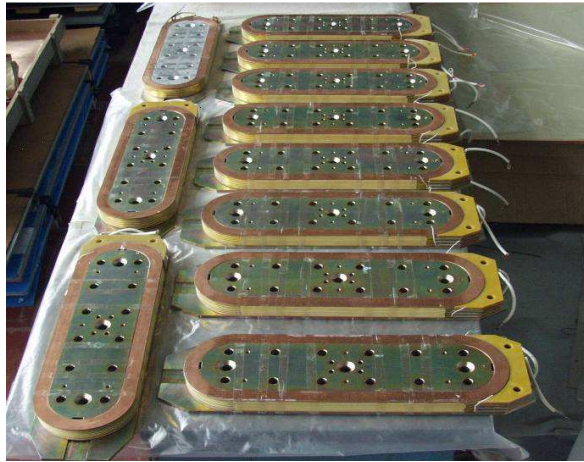
Figure 1. HTS 2G field coils.

Figure 2. Rotor assembly.

The field poles and rotor shafts are attached to the ferromagnetic rotor yoke (see fig. 3 – 5. The ruler at the photos is 1 m long). The rotor is covered with the rotating cryostat with thermal insulation Cryogel.

The stator with 120 slots consists of the electrotechnical steel sheets with the thickness of 0.35mm. The stator is water cooled (see fig. 6 – 8). The general view of 1 MVA HTS-2G generator is presented in Fig. 9 and 10.
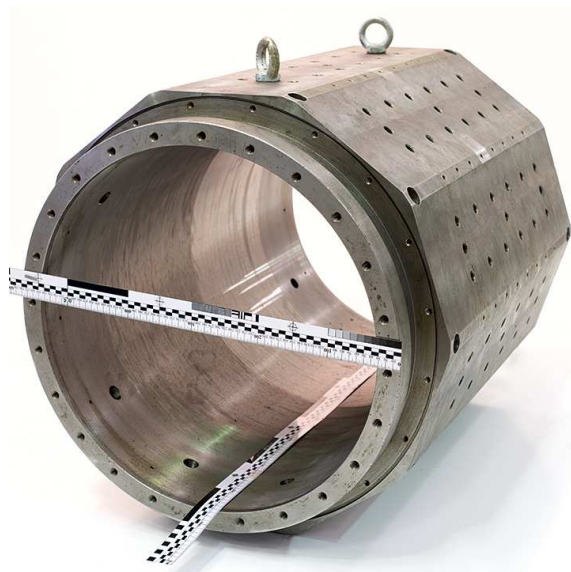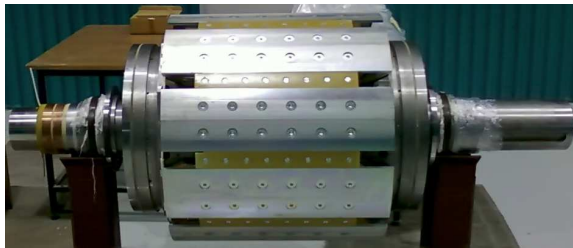

Figure 3. Rotor yoke.
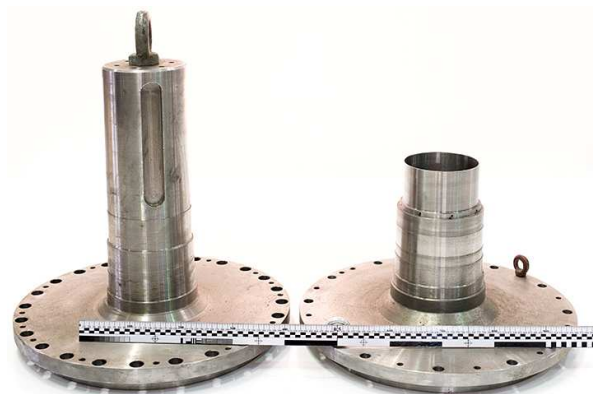
Figure 4. Rotor Shafts.

Figure 5. Rotor (without cryostat).
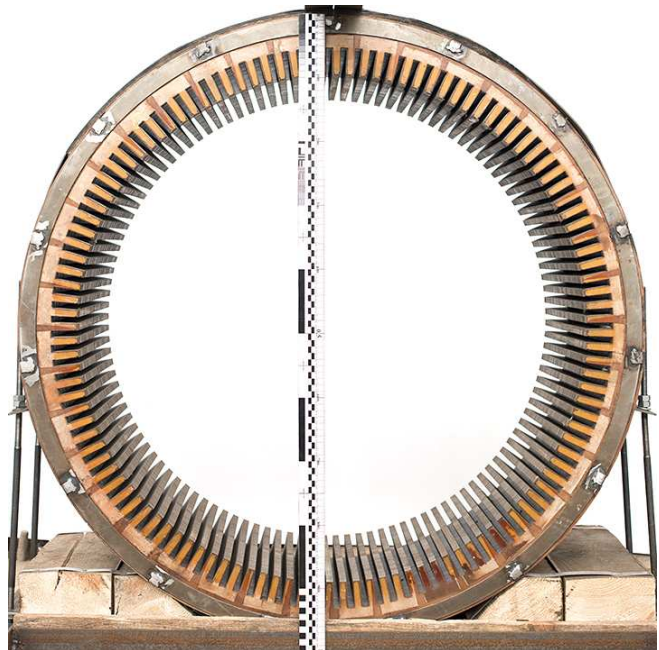

Figure 6. Stator without windings.

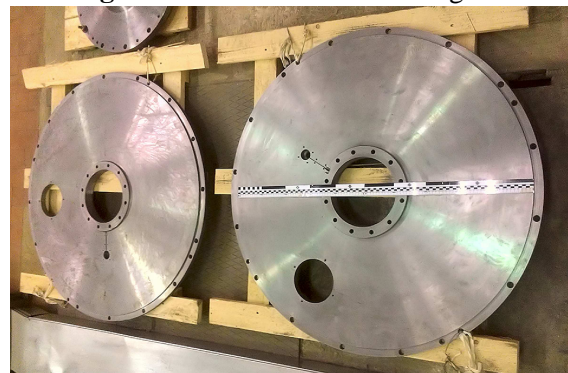**Figure 7**. Stator.

Figure 8. Flanges of the Stator.

Figure 9. General view of HTS-2G 1 MVA generator.

Figure 10. General side view.

3. Experimental results

The summary diagram of the measurement of the critical current (the criterion was 1 microvolt/cm) in the HTS-2G field coils 77 K is shown in Figure 11. The white stacks show the critical current values of the short samples in self field at 77 K. Grey stacks show the critical current value of the HTS field coils on ferromagnetic poles inside the generator. It can be seen that the critical current 2.5-time reduction which occurred due to the operating of HTS tapes in strong magnetic fields is about 0.7 T. This reduction should be taken into account in the design of the HTS-2G generator.

The No-load characteristics of HTS-2G 1 MVA generator are shown in Figure 12. The horizontal axis is DC current in HTS field coils. The vertical axis is the phase voltage. As it can be seen from fig. 12, the usage of HTS-2G field coils provide the magnetomotive force, which leads to the saturation of the machine magnetic circuit at the current value of ~30 A.

Load characteristics of generator are shown in Figure 13. The horizontal axis is AC phase current, the vertical axis is the AC phase voltage and output power.
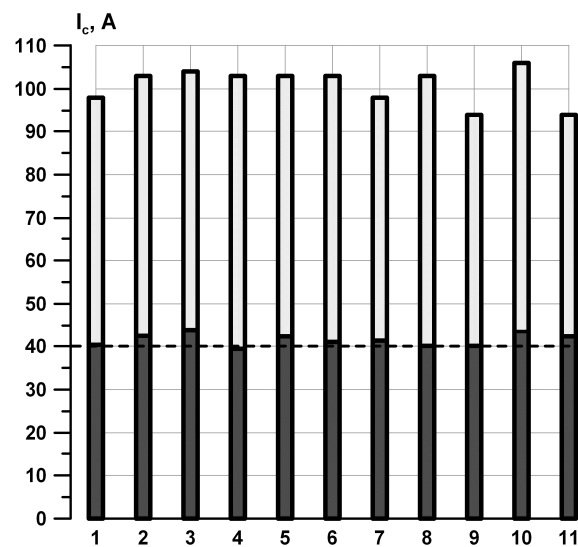

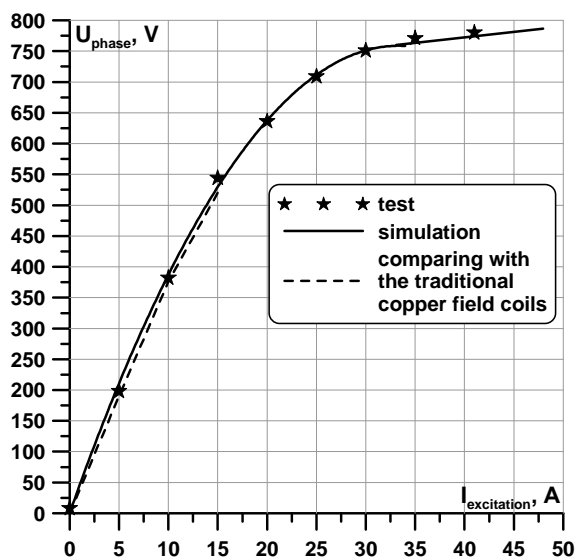**Figure 11.** Critical currents of HTS-2G poles.

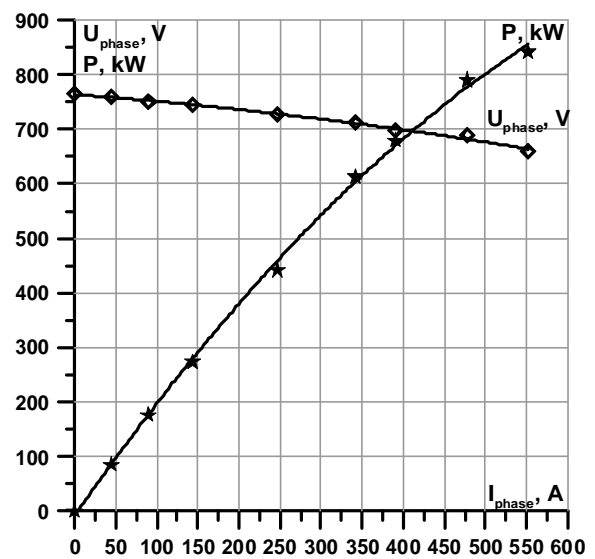**Figure 12**. No-load characteristic of HTS-2G 1 MVA generator.

Figure 13. Load characteristic of HTS-2G 1 MVA generator.

4. Conclusion

For the first time in Russia, the 1 MVA generator with HTS-2G tapes was designed, fabricated, and successfully tested.

This research will allow one to start future work, aimed at the development of the HTS-2G generator with output power of up to 50 MW.

5. Acknowledgments

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