NEW DESIGN OF HYDROGENERATOR POLES

Kuchinskaia Z.M., Ph.D Department of Hydrogenerators, Electrosila 139, Moskovsky pr., 196105 St.Petersburg, Russia

phone: +7 (812) 387 97 13, fax: +7 (812) 388 18 14, e-mail: kuchinskaya@elsila.spb.ru

Abstract

The excess of reactive power generated by power transmission lines is the reason for impermissible increase of voltage at the terminals of the length power transmission lines for consumers. One of the alternative decisions for this problem could become at the hydropower station hydrogenerators, specially designed or reconstructed for their possible operation at underexcitation. The problem hydrogenerator's operation with consume of reactive power from the net is caused, at first, by the stator core end parts heating. The new design of pole end plate with nonmagnetic part is used for the decrease of end parts heating. The experimental and calculation results of the hydrogenerators with new pole design are shown. There are some advantages of the split-design pole end plates using nonmagnetic pole end plates. The reliability, service life and the efficiency of hydrogenerators are increased due to decrease of the heating of the stator core end parts. The possibility of continuous operation of hydrogenerator operation at underexcitation is expanded. It is not necessarily to do the expensive compensating devices.

Key words

Hydrogenerator, complete pole end plate, underexcitation.

1. Introduction

The increment of the power transmission lines is due increase of the energetic equipment power. to Accordingly, the lengthy transmission lines have the essential values of the distributed capacitance's and, accordingly the voltage increase. So, because of the increase of the lengthy and voltage on the transmission lines, in different regions many power systems have difficulties in consequence of the excess of reactive power generated by power transmission lines. It is the reason for impermissible increase of voltage at the terminals of the power transmission lines for consumers. At the transmission line with rated voltage 500 kV, for example, the receiving terminal may be voltage increase to 539 kV; at the transmission line with rated voltage 220 kV - the voltage rise to 229 kV, at the transmission line with rated voltage 110 kV – the voltage rise may be to 119 kV. In order to avoid these dangerous phenomena in the power systems should be created expensive compensating devices - reactors or synchronous condensers, but this is involved with essential additional cost. The alternative decision for this problem could become the equipping of the power systems with generating units capable of consuming the excessive reactive power of the network or reconstruction of the existing equipment so that it will be able to consume the reactive power. Such equipment at the thermal power

stations can be asynchronized turbogenerators, and at the hydropower stations can be hydrogenerators, specially designed or reconstructed for their possible operation at underexcitation.

2. Design and Calculations

Large hydrogenerators, as rule, have essential limitations on operation with the consume of the reactive power, at underexciting. These limitations, first of all, are depend from the electromagnetic utilization of the active hydrogenerator capacity, which is defined by the linear load of the stator current. The linear load of the stator current is the current in the stator slot per slot division. Now, in modern electrical machine practice, for the design of the hydrogenerators with indirect air cooling, competitive at the world market, it is needed to have the value of the linear load of the stator current not less than 700 A/cm. The higher is this load, the narrow is the zone of continuous combinations of active and reactive powers at underexcitation. The zones of the continuously allowable loads for type constructions of hydrogenerators, depending on the power and linear load of stator current are presented at Fig. 1. These relationships have been obtained by empirical method as a result of processing the experimental data for many types of hydrogenerators with different sizes, loads and parameters.

The theoretical and experimental researches were done in 70-ies of the last century for the investigation of the problem hydrogenerator's operation with the consumption of the reactive power from the network or, other words, the hydrogenerator's operation at underexcitation. The special investigations under artificially created operation conditions with the consumption of the reactive power from the network have been carried out in the process of hydrogenerators tests besides standard, routine experiments. In doing so, careful study of electromagnetic and thermal field distribution in end stator parts and adjacent generator parts was carried out. As a result of these tests, it was stated that heating of stator end parts is a factor limiting the range of continuous allowable operation loads at underexcitation. At the high load's level other factors such as a boundary of static stability or minimum permissible excitation current, are not limiting. The curves of the reactive power versus active power at the leading power factor, represented at Fig. 1, have been obtained from the condition of limit permissible of the stator end parts.



Fig. 1. Diagram of continuously allowable loads for the hydrogenerators at the underexcitation

The main purpose of the tests is the creation of the calculation method, which could allow to foreseen in advance the limitations of the allowable mode of operation, to elaborate some recommendations on design and operation, and, finally, to try find the decisions, which would principally allow the problem of the stator end parts heating.

At first of all, to check and to confirm the results of sufficiently difficult and labor-intensive calculations, a special model of hydrogenerator's active part has been built, where stator can move and take any positions relative to the rotor. Thus, the position of ferromagnetic boundaries can be practically changed on this model in any way. The detailed investigations of the electromagnetic field distribution and of the active parts heating in the end parts allow to formulate the recommendations on choose of the optimal geometry for end parts.

The analysis of the investigations results, and, further, analysis of the calculations results, has shown, that the axial component of the electromagnetic field in the end parts of the hydrogenerator's stator core, which is due to the electromagnetic rotor field, finally causes the eddy current short circuit in the stator core sheets, in the stator core end plate in the tangential plane. Accordingly, in the stator end parts one can see the increase of the losses, caused by the eddy currents, and so, the increase of heating. The value of the axial component of the electromagnetic field finally depends from the configuration, mutually disposition and design of the end parts as generator's rotor, as generator's stator.

There were done some recommendations for the achievement of optimal geometry of stator core end parts on the base as of the laboratory tests, as of the test results on operative hydrogenerators, – the "steps" on stator core end packages, the different stator length and rotor poles length, and the most radical means at the high electromagnetic loads – using of rotor end plates from nonmagnetic materials.

Special investigations have been carried out on the number of hydrogenerators. In 1975 year at hydrogenerator Zeyskaya Hydro Power Plant with rated output 215 MW there was done unique experiment. From one side of hydrogenerator the pole end plates were the usual design, and from other side – the pole end plates were done complete, split-design, from two parts. One part of end plate, nearest to stator, was manufactured from nonmagnetic material. Application of complete pole end plates allowed decreasing the axial component of the magnetic flux density and the average stator end parts heating.



Fig. 2. Distribution of flux density on pole end plate surfaces for hydrogenerator of Zejskaya HPP.

The experimental results are shown at Fig. 2 – the distribution of the axial component of the magnetic flux density on the surface of the pole's end plates for the hydrogenerator Zeyskaya Hydro Power Plant. The computational results and experimental results on the temperature distribution at the end package of the stator core for the same hydrogenerator are shown at Fig. 3, as for magnetic, as for nonmagnetic pole's end plates.

Computational method is based on the common mathematical apparatus by FEM. It was solved the problem of the distribution of the stationary magnetic field, of the eddy current electromagnetic field, caused by the axial component of the stationary magnetic field; the losses due to eddy current and also the problem of the heating distribution in the end parts of the stator core. At the Fig. 2 is shown, that the maximum value of the axial component of the magnetic flux density from the side of the magnetic pole's end plates is less in 2,6 times, than from opposite side. The average heating of the stator core end packages from the side of the complete nonmagnetic pole's end plates decreases more than 30% (Fig. 3).

The comparative tests of the synchronous motors 22 MVA, 10 kV, 375 rpm having nonmagnetic and magnetic pole end plates showed similar results: the axial component of the flux density near the stator bore was reduced by more than 2 times and losses in the stator core were reduced by 60 kW that is equivalent to the increase of efficiency by 0,3%.



55 - calculation data57.6 - experimental data

Fig. 3. Temperature distribution in the stator core end package for hydrojenerators Zeiskaya Hydropower Station at underexcitation

Widespread industry the use of the pole's new design begins from the end of seventies of the last century. This construction at the first time was used at the large hydrogenerators of Sayano-Shushenskaya Hydro Power Plant. Hydrogenerators of Sayano-Shushenskaya HPP have direct water cooling of the stator winding and have linear current load 1200 A/cm and consequently a very high magnetic field strength in the generator end parts. The use of the complete rotor pole's end plates allows achieving practically equally low heating of the end packages and average packages of stator core. The comparison of the thermal state of the stator core end packages for Sayano-Shushenskaya HPP hydrogenerators with the heating of similar packages of Krasnoyarskaya HPP hydrogenerators, having magnetic rotor pole end plates, has clearly shown a new pole design efficiency. There were compared the temperature of the stator end parts for two large hydrogenerators - of Sayano-Shushenskaya and Krasnoyarskaya Hydro Power Plants at the same load (at rated output and at power factor equal unit). Hydrogenerators of Sayano-Shushenskaya HPP have the nonmagnetic pole end plates, and hydrogenerators of Krasnoyarskaya HPP have magnetic pole end plate. The

temperature of the stator core end packages for generator of Sayano-Shushenskaya HPP is less, than the temperature of the stator core end packages generator for Krasnoyarskaya HPP: from the stator bore – at 62° C; at teeth base – at 33° C, from the stator yoke – at 30° C. In this case, the heating of the middle packages of the both hydrogenerators is practically the same. This circumstance was one of the reasons, why at the renovation of the Krasnoyarskaya HPP hydrogenerators, involving the traditional replacement of the stator core and stator winding, the excitation system and the cooling system, the pole cores were also replaced while keeping the existing pole coils. The reconstruction of the pole cores consists in the change of the pole end plates material partially on the non-magnetic material.

During last 25 years it was totally manufactured more than 1350 rotor poles for 23 new hydrogenerators and for 6 reconstructed hydrogenerators with use of the complete rotor pole's end plates with nonmagnetic part near the air gap. The experience of the use of new design of poles, obtained more than 25 years, confirm their efficiency completely. The main data on the hydrogenerators, using the new pole design, are given in the Table.

Nº	Hydropower Station	Country	Number of Units	Output	Voltage	Rated speed	Year of
				MW	kV	rpm	manufacture
1	Sayano-Shushenskaya	Russia	10	640	15,75	142,8	1977-1984
2	Purnari	Greece	3	100	15,75	150	1978-1979
3	Piedra-del-Aguila	Argentina	4	370,5	15,75	125	1989-1990
4	Aguamilpa	Mexico	3	323,9	13,8	150	1992-1993
5	Krasnoyarskaya	Russia	5	500	15,75	93,8	1994-2001
6	Burejskaya	Russia	3	335	15,75	125	2001
7	Jylhama	Finland	1	21,8	10,5	115,4	2002

As rule, principally the split-type pole end part is made from two parts: the bottom steel part and the top nonmagnetic part. These parts are fastened together for reliability with an interlocking device. The choose of the materials for pole end plates is imposed under the circumstances: it is desirable to make the end plate part near the pole base as magnetic one in order to avoid the increase of the magnetic flux density and, as a consequence, the field current; the pole end plate part near the stator is to be nonmagnetic in order to increase the magnetic resistance on the path of rotor magnetic stray field and, consequently, for the decrease of the edge effect. The design realization of the complete pole end plate with nonmagnetic part near the stator is shown in Fig. 4. As a material of nonmagnetic end part, a titanium-based alloy is used. Preference was given to the titanium-based alloys as possessing a high mechanical strength at substantially lesser (as compared with steel) specific gravity and simultaneously a high electric resistance. That is very important as at the same time it allows surface losses on the pole shoes due to the magnetic field pulsation with a toothshaped frequency to be reduced. Thus, the selection of titanium alloy pursues several different purposes, as electromagnetic, as mechanical character.



Titan Steel

Fig. 4. Nonmagnetic pole's end plate

The problem of stator end parts heating is not so actually in hydrogenerators of essentially lesser unit capacity, than in hydrogenerators for Sayano-Shushenskaya and Krasnoyarskaya hydropower Plant. But it is very important, that the use of the pole end plates, made of nonmagnetic materials, allows the range of permissible operation at underexcitation to be substantially expanded. This is illustrated in Fig. 5, where is represented the diagram of continuously allowable loads for the Burejskaya Hydro Power Plant hydrogenerator at the operation with consumption of the reactive power from the net.

There is an interesting example of the use of new pole design at hydropower station in Finland. In 2002 for

hydropower station Jylhama in Finland were reconstructed by Electrosila three hydrogenerators with rated output 21,8 MW, with rated rotation speed 115,4 rpm. Two generators are manufactured with usual steel pole design, because it is not necessary to make nonmagnetic pole end parts for generator with small output. But it is very interesting for Customer to have at the same power station the generators with principally different construction of pole end parts, and the third generator – for the first time in Finland for the demonstration of new design decisions - has new construction – nonmagnetic pole end plates. In this case the end plate thickness is not too large due to the small hydrogenerator's power, and in the first time there is used the non-complete, but totally nonmagnetic pole end plate. It is interesting experiment for the definition of difference between flux density, heating, losses in the stator end parts, possibility of operation for the same hydrogenerators, but with different construction of the pole end plates. Even for generator with small capacity 21,8 MW the efficiency increases at 0,01% due to the using of new pole design with nonmagnetic part of pole end plate.



Fig. 5. Diagram of continuously allowable loads for the hydrogenerator Bureyskaya HPP at the underexcitation

3. Conclusion

The use of complete rotor pole end plates with nonmagnetic part near stator for hydrogenerators is used more than 25 years of exploitation. The efficiency of the use new design of poles is proved during this time. Advantages of the split-design pole end plates using nonmagnetic pole end parts are as follow:

- heating of the stator core end parts is reduced. Thus, the generator reliability and service life is increased;
- the range of continuous permissible duties of hydrogenerator operation at underexcitation with consumption of reactive power from the network is expanded that enables the problems of power transmission for a long distance to be solved without application of expensive compensating devices;
- losses in the stator end zones are reduced and the efficiency of hydrogenerators rises.