Cut Out Bars FEM Simulation of Large Hydro Generators

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***Abstract*- In this paper, the simulation of a large synchronous machine operating with asymmetrical stator windings is presented. The main objective on this man study is to determine the ability of the machine to operate at nominal load with many cut coils in different phases. This paper reports a finite element electromagnetic simulation of an existing hydro generator of 32.5 MVA, 13.2 kV, 60 Hz, 68 poles, 432 stator slots with 1 and 4 stator coils of phase B cut out and bypassed. The simulation results of this configuration are detailed and compared with experimental results.**

***Index Terms* – coils; electromagnetic analysis; electromagnetic fields; finite element method; hydroelectric power generation and numerical analysis.**

I. Introduction

With the advanced of powerful computer, finite element method started to be used more frequently to determine many parameters of large rotating electrical machines such as: the core loss distribution; and the damper bar losses, voltage harmonics [1-2].

In large hydro electrical machines, when a stator winding failure occurs it is possible to make a temporary repair by cutting out and bypassing the failed coils, keeping the safety operation of the machine, and permitting a quick return to service of the machine [3].

Depending on the number of bypassed coils and the there positions in the winding, the machine can operate even at full load in case of the winding temperatures limits of different circuit are not exceeded; however in certain cases, the machine need to be de-rated to keep the level of the current in the circuit in the acceptable range and at the same time the corresponding temperature.

Actually a few publications regarding cut out coils are presented in the literature. Academic books [4, 5] only cite that the coils can be let cut out and the machine can be restarted after a failure but no further explanations are presented. Another publication [6] analyzed the performance after disconnecting damaged coils for 3-phase motors. The constant and pulsating torques, the losses, the current distribution and the magnetic pull were covered in the paper using an analytical method and experimental results. In addition, the performance of synchronous machines operating with unbalanced stator coils was analyzed by [7] and the electrical and mechanical effects concerning the mechanical forces associated with the circulating current were presented.

A hydroelectric generator with bypassed stator coils was studied in [8] and the unbalanced split-phase stator winding currents and the stator and rotor temperature were measured. Comparing the current measured with the one calculated in reference [3], an overestimation of 0.2 p.u. of the calculated current. Reference [3] provides a conservative calculation method to predict the magnitude of circulating current and actual measurements of each winding parallel circuit current may be necessary is higher accuracy is required. The finite element method has not been used yet to calculate the core loss of a machine with cut out and bypassed stator windings.

In this present paper, an investigation of the performance characteristics of a large hydro electrical machine with cut out and bypassed stator winding based on a finite element method is presented. The simulation results of this configuration are compared with experimental results.

II. Experimental Results

Two variables are used during the process of comparison between experimental tests and simulation results: total magnetic core loss and air gap magnetic flux density.

The studied generator in this paper has a rating of 32.5 MVA, 13.2 kV, 60 Hz, 68 poles, 432 stator slots with 1 bypassed coil in phase B.

The total magnetic losses measured at no-load were 176 kW. During short-circuit test, the fluctuations of the rotor current have resulted in significant fluctuations in the stator current. This instability was so important that it was difficult to derive a reliable value for the stray losses.

III. Simulation Results and discussions

Hydro generators usually present fractional slot windings; this strategy is used to reduce the harmonics e.m.f. because the fractional windings give a smaller distribution factor. However, when numerical methods are considered for uprate the machine, the presence of a fractional machine increases the simulation time sometimes in more than 200%.

In the electrical generator with bypassed coils in the stator windings, the electromagnetic symmetry is not only determined by the number of slots per pole per phase, but also for the spatial distribution of theses bypassed coils. For FEM simulation, the complete generator has to be modeled resulting in a large number of poles (68 poles in this case) to be simulated.

For this paper, six simulations were performed: open-circuit symmetrical machine; open-circuit with one cut bar; open-circuit with four cut bars; 86% nominal load symmetrical machine; 86% nominal load with one cut bar and 86% nominal load with four cut bars.

In the open-circuit simulations the computed core losses was approximately 155 kW for the three cases. It has to be noted for instance that for 2D model simulation does not include the induced losses in the end plates and some additional losses (3D effect), so the computed result should be higher. Even though, the value is close to the measured value of 176 kW.

For load condition, the simulation was only performed at 86% of the nominal load because of the water restrictions at the time of the year when the measurements were done. The computed magnetic flux distribution for the symmetrical windings and with 4 cut out coils in the stator are shown in Fig.1; where small differences in the flux lines can be observed.

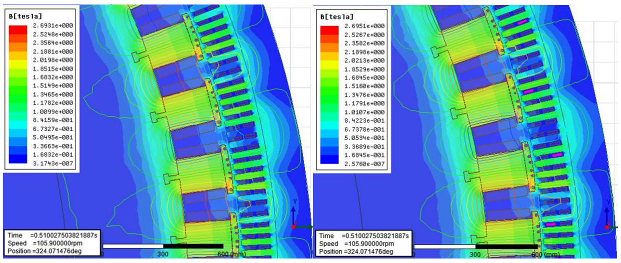

Fig. 1. Magnetic flux density and flux lines distribution for a symetrical and assymetrical machine with 4 bars cut out (86% of nominal load).

The computed radial magnetic flux density with and without cut coil is shown in Fig.2. It can be observed that the magnetic flux density pulsations are higher when the machine presents one cut coil compared the healthy machine without any cut coil. The computed terminal voltages in case of 4 bypassed coils and in case of healthy unit (without cut coil) are shown in Fig. 3; where higher harmonics orders are observed in the case with 4 cut coils.

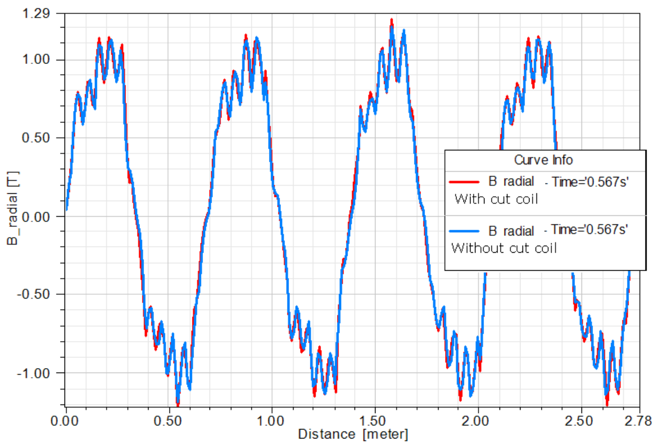

Fig. 2. Radial magnetic flux density for symmetrical and assymetrical machine (86% of nominal load).

At load operation, a small unbalance current is observed in the generator's phases when the phases are cut out and bypassed. Table I shows the computed phase currents for the three configurations (symmetrical, one bypassed coil, 4 bypassed coils). In future other many other situations can be studied such as the impact of removing completely one circuit in arbitrary phase of the generator.

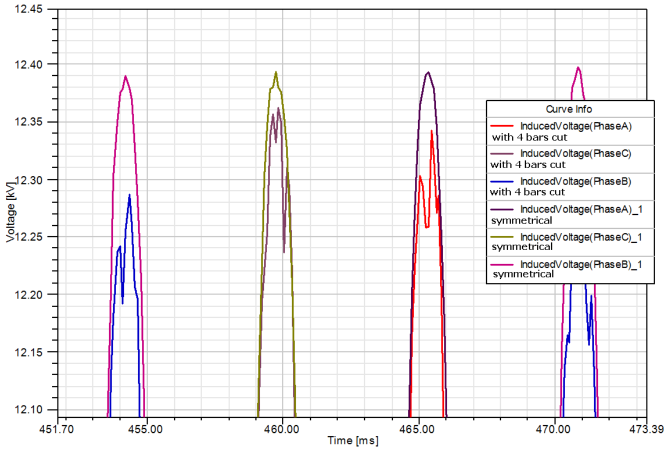

Fig. 3. Phase voltage for symmetrical and assymetrical machine (86% of nominal load).

TABLE I
CURRENT PER PHASE – LOAD OPERATION (86%)

Case	Phase Current rms [A]		
	Phase A	Phase B	Phase C
Without cut bar	1329	1329	1329
1 cut bar phase B	1322	1321	1326
4 cut bars phase B	1322	1320	1324

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