1- Power electronics in hydro electric energy systems – A review

2- Review of techno-economic and environmental aspects of building small hydroelectric plants – A case study in Serbia

3- International Energy Agency (IEA), 2001, Guidelines for Hydroelectric Generator Upgrading, Technical Report, The Hydro Power Upgrading Task Force.

4- Hydro Generator High Voltage Stator Windings: Part 1 – Essential Characteristics and Degradation Mechanisms

5- IoT-based Pico-Hydro Power Generation System using Pelton Turbine

6- CHALLENGES AND OPPORTUNITIES OF ELECTRIC MACHINES FOR RENEWABLE ENERGY (INVITED PAPER)

7- Partial Discharge Patterns in High Voltage Insulation

8- Investigation of Partial Discharge Activity and Insulation Life of a Large Hydro Generator

9- Hydro generator high voltage stator windings: Part 2 – design for reduced copper losses and elimination of harmonics

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**Introduction**

A recent urge towards the use of renewable energy as a source for electricity production has formed due to a growing concern for fossil fuel consumption and depletion which in turn eventuates to release of greenhouse gases to the atmosphere and destruction of natural resources [1-2].

Hydropower being one of the major sources amongst the various sources of renewable energy, holds about 17 percent of the global power generation [2-4]. Hydroelectric systems consist of various components such as generator, turbine, control system, etc. [5]. Considering the generator component of the system, although AC machines have shown a proper performance in tackling the renewable energy sources, there is continuing research on utilizing other machines for this purpose. Due to their mature technology and high power ratings, synchronous generators have been the most common type of the machines used in large hydropower stations. Synchronous generators have the disadvantage of large amounts of field loss and requiring refurbishment of slip rings and brushes. On the other hand, induction generators and permanent magnet synchronous generators are more desirable for small hydropower systems because of the high fluctuations in water flow [6].

Renovation of hydroelectric generators is of high concern [6]. Partial discharge (PD) is one of the factors giving rise to this issue. PD is an electrical discharge, which does not link the electrodes between an insulation system completely under high electric field stress [7]. This phenomenon results in the aging of the insulation system. Partial discharge shows itself where the semi-conductive and stress-grading coatings of high voltage bars overlap. Reapplying the coatings can be useful for the repairment. However, the effect of this method will vanish after a short while, and it calls for regular repairs [8].

Another important topic regarding the hydro generators is copper loss reduction. For this matter, acquiring an acceptable coil design can lead to better thermal characteristics and enhanced heat dissipation [9]. Moreover, design of loads connected to hydro generators requires to be employed with sinusoidal EMF. Geometrical improvements can be applied to the rotor pole shape of the salient pole synchronous generator to achieve a better sinusoidal approximation for the rotor MMF. In addition, relative positioning of the damper winding and the slots in the stator side has a significant role in diminishing the slot ripple and producing a smoother MMF waveform [10].

In this study, a salient pole synchronous hydroelectric generator will be designed to meet some pre-defined specifications. In the first step, an analytical calculation and sizing will be carried out. Next, an FEA analysis using ANSYS MAXWELL software will be performed by implementing the same dimensions resulting from the first step and defining suitable boundaries and well-defined meshing. Finally, there will be a comparison between the analytical and FEA results to discuss the possible inconsistencies.

Analytical Calculation & Sizing

* Choose a specific machine constant by choosing proper values for the magnetic and electrical loading, current density etc.

The larger the value of machine constant, the smaller is the volume (D2L) of the machine, and this will be effective in reducing the cost. Machine constant is larger if machine is designed for higher specific magnetic and electrical loadings. Due to the limitations in the ranges that these two values can be chosen from, there should be a compromise.

Designing with higher magnetic loading, will give a rise to the possibility of saturation, hence core losses will increase, and as a result the efficiency will decrease, and the temperature will rise more which will demand better insulation and cooling. In addition, with higher magnetic loading, more magneto-motive force is required to pass the flux through the airgap, which increases the magnetizing current resulting in lower power factor. But in the case of a synchronous alternator, magnetizing current is not much of an issue since it is provided with dc excitation.

If designed with high electrical loading, there will be large amount of copper loss in the windings. This will cause issues related to heat dissipation in the slots and thermal expansion. High value of electrical loading should also be taken into consideration when selecting the insulation material and thickness.

In the recent years, the insulation production has gotten more advanced. Therefore, in this design a rather high electrical loading has been chosen to compensate for the low magnetic loading.

Magnetic loading (avg): 0.75 T

Electrical loading (rms): 55000 A/m

For the calculation of the machine constant, is required and it depends on the winding design. Here, machine constant can be calculated for , and after the winding diagram is decided, it can be recalculated with the actual value of .

Hence, it will be tackled here:

When choosing the number of slots, tooth thickness is an important consideration

* Define the rough dimensions (airgap clearance, rotor diameter, axial length)
* Choose the winding configurations (number of slots, number of coils, cable size etc.)
* Calculate the other parameters such as the teeth/slot dimensions, back-core thickness etc.
* Material selection (laminations, magnet grade etc.)
* Electrical circuit parameter estimations (induced voltage, flux per pole, phase resistance, phase inductance etc.)