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## HYBRID EXCITED SYNCHRONOUS MACHINE FOR MICROHYDROPOWER UNIT

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*The hybrid excited synchronous machine with axial magnetic flux for microhydropower unit and its operation mode is considered in this paper. A mathematical model of synchronous machine with hybrid excitation in the rotor coordinate was obtained to simulate voltage stabilization process depending on drive speed and load. To validate the results of simulation an 8-pole prototype was tested.*

**Keywords:** *hybrid excited synchronous machine, axial flux, stabilization.*

## СИНХРОННА МАШИНА З ГІБРИДНИМ ЗБУДЖЕННЯМ ДЛЯ МІКРОГІДРОЕЛЕКТРОСТАНЦІЇ

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*У роботі розглядаються режими роботи синхронної машини гібридного збудження з осьовим магнітним потоком для мікрогідроелектростанції. Отримано математичну модель синхронної машини з гібридним збудженням в координатах ротора для імітації процесу стабілізації напруги залежно від швидкості обертання та навантаження. Для перевірки результатів моделювання був протестований 8-полюсний прототип.*

**Ключові слова:** синхронна машина з гібридним збудженням, осьовий магнітний потік, стабілізація.

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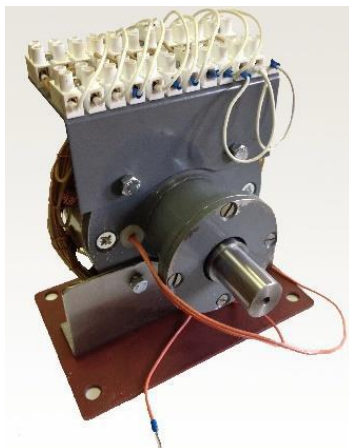
**INTRODUCTION.** The part of renewable sources generated energy is growing every year. In particular, hydropower has a high energy resource, the lowest cost of electricity production, high reliability indicators. On the territory of Ukraine there are over 60000 small rivers and watercourses flow with a total length of 185.8 thousand kilometers. Today in Ukraine there are 84 small hydropower plants with a total capacity of about 107 MW in operation. At that time, as in Sweden, hydropower plants produce about 40% of electricity. General forecast for the development of small hydropower in Ukraine is 1,240 MW, which is almost 11 times more than the realized potential.

Permanent magnet generators are widely used in small hydropower plants and windgenerators due its high efficiency, reliability and simplicity. The usage of axial flux permanent magnet generators is more likely in hydropower units due small axial size, possible gearless design etc. The main disadvantage in permanent magnet generators is the inability to control the magnetic flux.

Hybrid excited synchronous generator have advantages of both electromagnetic and permanent magnet excitation systems. They have higher efficiency than machines with electromagnetic excitation (including brushless synchronous generators) and still have ability to change the magnetic flux value in air gap in some defined range. Frequently hydropower unit consists of turbine (with or without speed drive controller), charge controller, accumulators and inverter. The price of inverter is comparable with the cost of generator, e.g. 20 kW inverte costs about \$5000, while the price of synchronous permanent magnet generator is about \$4800.

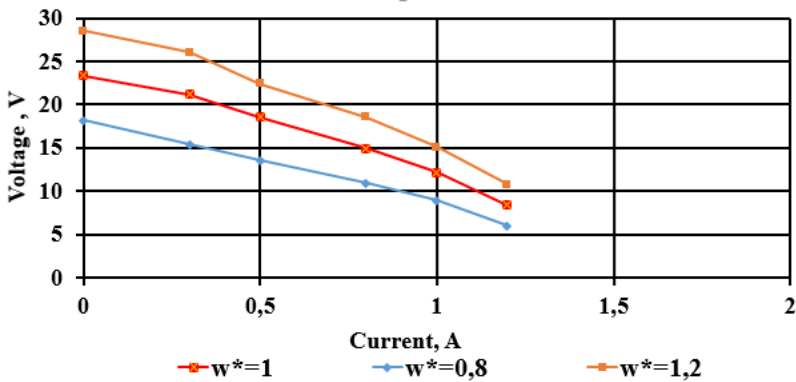
The total price of hydropower unit can be reduced and simplified by using hybrid excitation synchronous generator that runs on unmanaged rectifier. This article deals with issue to maintain the value of output generator voltage depending on drive speed and load coefficient.

**EXPERIMENTAL PART AND RESULTS OBRAINED.** To validate the simulation results an 8-pole prototype was designed and tested. The general view of it is presented at the fig. 1.



**Fig. 1. A hybrid excited synchronous generator with axial flux**

The experimental load characteristics depending on different drive speed are shown at the fig. 2.



**Fig. 2. Load characteristics at different drive speed**

At fig. 2: blue line – relative speed – 0,8; red line – relative speed – 1; orange line – relative speed – 1,2.

The voltage difference in no-load is about 45% and almost 40% at overload. The issue to maintain the reference voltage depending on drive speed and load was practically solved with help of Arduino Nano and voltage, current and speed sensors. The maximum excitation power to generator power ratio is 25% to provide reference voltage – 24V in a range of  $\pm 50\%$  load factor. The error between experimental and simulation results is explained by unaccounted magnetic losses and non-linear dependences.

**CONCLUSIONS.** The use of synchronous generators with hybrid excitation allows to reduce the cost of the entire microhydropower unit in the case of work on an unmanaged rectifier compared to a machine that runs on an inverter. The reference voltage in a specific machine (prototype) is possible to obtain within of  $\pm 50\%$  load changes in  $\pm 20\%$  speed range with a maximum excitation power to generator power ratio is less than 10%.

The use of high coercive permanent magnets in machines with hybrid excitation increases the weigh-to-power ratio, but at

the same time reduces the range of regulation of the total magnetic flux. The growth of control region is should be made at the design stage for a specific task by changing the ratio of constant (permanent magnets) and variable magnetic fluxes (field excitation current) by varying the volume of permanent magnets with respect to the zone of electromagnetic excitation.

The mathematical model of synchronous hybrid excited machine in the rotor coordinate system allows to simulate processes of stabilizing the voltage depending on drive speed and load that is important for specific areas of industry such as microhydropower units or auxiliary power units. The comparison between simulation data and experimental results shows low error.