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ANALYSIS OF ELECTROMECHANICAL POWER TRANSFORMERS APPLIED IN SMALL HYDROENERGETICS

Mariam SAGHATELYAN[1,*], Marija MEIŠUTOVIČ-AKHTARIEVA[2]

[1] *National Polytechnic University of Armenia, Yerevan, Armenia*
[2] *Kaunas University of Technology, Kaunas, Lithuania*

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Abstract. At present, in Armenia, hydraulic resources of slow-flowing rivers allow to solve the problem of power supply to small consumers rather efficiently. The electric power generated in small hydropower plants has the lowest prime cost in comparison with that of the power generated by other renewable and traditional power sources. At their construction, in contrast to powerful hydropower plants, the ecological damage (land flooding, destruction of fish farming, the change in the balance of the local climatic condition, etc) are practically excluded. In the present work, issues on applying different types of electric generators in small hydroenergetics are considered. The main advantages, disadvantages and also recommendations on applying electrical generators at their utilization in small hydropower plants are introduced. The developed external damper system for the synchronous hydro aggregate is introduced.

Keywords: hydro generator, synchronous generator, induction generator, a double-fed machine, inductor generator.

Introduction

At present, on the rivers and water conduits of Armenia, many small hydropower plants (SHPP) are constructed. The development of hydropower in Armenia gives an opportunity to supply electric power to the remote settlements situated close to the water areas. Small hydro energetics is devoid of many disadvantages of the powerful hydropower plants. It is one of the most environmentally safe methods of electricity generation especially in the case of using small water resources. From the viewpoint of the ecology the advantages of the SHPP are the followings: mitigation of the climate global change impact on the environment through reduction of the CO_2 emission, minimal areas of the flooding and building. During construction and operation of the SHPP the natural landscape is preserved, ecosystem load is practically absent (Yasinskiy, Mironenkov, & Sarsembekov, 2011). Many SHPPs are successfully functioning in the Republic of Armenia (RA), and the construction of new ones is planned. The statistical analysis of the 40 functioning in RA SHPPs of 1…5 MW, belonging to different river basins has shown that the water head in the considered SHPPs is in the range of 51.2…575 m, while the consumption – 0.45…6 m^3/sec. Upon that, the average annual values of the RA SHPPs are: water head – 167 m; water consumption – 2 m^3/sec; the SHPP power – 2200 kW; the generated power – 8,15mln KW/h.

The Figure 1 shows the share of total primary energy supply (TPES) in 2015 in Armenia. Share of TPES excludes electricity trade.

The Figure 1 shows that 6% of total primary energy supply goes to hydroenergy. According to the results of 2016 in the structure of hydroenergetics of Armenia the electricity generated by the SHPP has reached to 13%.

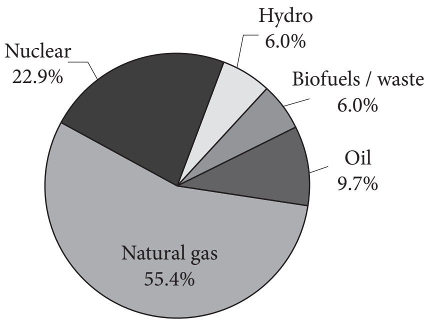

Figure 1. Share of total primary energy supply in 2015 in Armenia

*Corresponding author. E-mail: *mariamdil@mail.ru*

In connection with this, designers and entrepreneurs should solve the task of the optimal selection of the generator type for those HPPs. In small hydroenergetics, all the modern types of generators of alternating current are used. As it is known, synchronous generators are widely used due to their good regulating properties. However, in recent years, induction generators, double fed machines, inductor generators have also found application (Development Scheme of Small Hydropower Plants in Armenia, 2009).

1. Synchronous generators

The advantages of synchronous generators are the possibility of generating reactive power, the simplicity and accuracy of voltage regulation when operating on stand alone load, the strong relation between the generator frequency and the rotational speed, the high efficiency. Synchronous generators from maximum to minimum values of power characteristic of small hydroenergetics are used. The disadvantage of synchronous generator is the complexity of the structure as compared to that of generators of other types, particularly because of the presence of the excitation winding on the rotor and the contact system of the excitation winding supply. As a result, synchronous generators have larger sizes, weight and cost than other types of generators. Recently, practically for the whole range of powers of small energetics, synchronous generators with brushless excitation have come into use. However, brushless excitation does not completely eliminate the structural complexity of a synchronous generator. At present, in the power range of 1 MW and above, synchronous generators of classical performance are preferably used (Ramos, Betâmio de Almeida, Manuela Portela, Pires de Almeida, 2000; Vol'dek, 1978; Pyrhonen, Jokinen, & Hrabovcova, 2008; Mishra, Singal, & Khatod, 2012; Tes, 2017a).

In case of power of the SHPP is of lower than 300…500 KW, industry does not offer multi-pole, low-speed generators which have large weight-size parameters, in connection with what, in low power SHPPs, general-purpose industrial synchronous generators with a rotational speed of 500 rmp and above are used. In this case, for matching the rotational speeds of generators and turbines, multipliers are used (Tes, 2017a).

As it is known, the synchronous generators are equipped with a damping winding which damps the fluctuations of the generator rotor. The fluctuations can be occurred due to any sudden or abrupt changes of the operation mode of the synchronous machine as well as due to sudden increase of the rotational moment of the hydro turbine. The asynchronous moment is created by the damping winding. This asynchronous moment tries to decrease the rotation speed of the inductor when it is increased relation to the average rotational speed and vice versa. Simultaneously, the damping winding influences on increasing of the electrical system stability. The external damper system for the hydro aggregate of the SHPP was invented and patented in order to improve the operation mode of the synchronous generator and to increase stability of the hydro aggregate and the system as a whole. The external damper system is an asynchronous machine with phase rotor which is installed on the shaft of the hydro aggregate and operates in parallel with the internal damper system. The developed system decreases the amplitude of the hydro aggregate fluctuations and damps them (Mailyan & Sagatelyan, 2017; Saghatelyan & Mayilyan, 2016).

2. Synchronous generators with permanent magnets

Synchronous generators with permanent magnets are also used which differ from ordinary synchronous generators by a simpler structure and reliability. The absence of the excitation winding on the rotor leads to the complexity of regulating the output voltage: the voltage regulation and stabilization at the output are not practically ensured. However, they are widely used at rectified loading. The disadvantage of the generator with excitation from permanent magnets is also the high cost of the latter and the complexity of the rotor structure connected with the magnet mounting (Vol'dek, 1978; Pyrhonen et al., 2008). Industry offers generators with permanent magnets of a power of up to several dozens of kilowatts, more rarely – up to a few hundred, with a rotational speed from 200 to 300 rpm and above. Because of deterioration of the cost and weight-size indices a low-speed generator with permanent magnets of small power is as difficult to make as are generators of other types.

3. Induction generators

Induction generators can also be used almost in all power ranges of small energetics. The advantage of induction generator is that their cost, weight and sizes are smaller than those of a synchronous generator of the same power. They should be used to reduce the capital expenses at constructing SHPPs if the requirements get to the maintenance expenses are not high. An important advantage of an induction generator is the low sensitivity to the short circuit and the high degree of protection from external impacts. The low sensitivity to the short circuits is conditioned by the deexcitation of the induction generator at a short circuit. The high degree of protection is easily ensured due to the simplicity of the structure (Ramos et al., 2000; Vol'dek, 1978; Pyrhonen et al., 2008; Mishra et al., 2012; Tes, 2017b).

The disadvantage of an induction generator is the consumption of reactive power consumed from the network when the generator operates paralelly with the network. For induction generator to operate on a low power network or on an autonomous load a battery of capacitors is used for generating reactive power. The battery deteriorates the weight-size and cost indices of the induction generator. The efficiency of applying an induction generator increases in case of an active load. The active load requires application of capacitor batteries of relatively low power.

In case of inductive load, the battery of capacitors should provide the generator and the load with reactive power (Vol'dek, 1978; Pyrhonen et al., 2008).

The main disadvantage of an induction generator is the difficulty of regulating the voltage and frequency at operating on an autonomous load or on a low power network as it is possible to regulate the voltage only on the generator loads.

4. Double-fed machine generators

Fundamentally new possibilities for generating active power are generator complexes (GC) based on the double-fed machine (DFM). The mentioned complexes include a generator and a frequency converter (Shakaryan, 1984).

Due to a wide range of possibilities and high speed regulating properties, the DFM – generator occupies its place among the alternative GCs, and, by advantages, especially in hydrosets of low power.

The generator is an induction machine (IM) with a phase rotor whose stator is connected to the network, while the rotor is supplied by a semiconductor transformer of frequency (TF). The TF voltage of the IM rotor circuit is practically directly proportional to the slip frequency. By changing the rotor supply frequency, the angular speed of the generator shaft can be regulated which can ensure the synchronous operation of the GC with the power system in a wide range. This allows to regulate the power supplied to the net and ensure the quality of the generated electric power.

The frequency transformers are built according to the power circuit, allowing to transmit active power in both directions. The fixed power of the TF is directly proportional to the maximally permissible slip frequency and allows to regulate the power by changing the electromagnetic moment of the generator. Thus it becomes possible to reduce the time of transient processes dozens of times in comparison with that of GCs maintained at present on the basis of synchronous generators, operating paralelly with the network.

The main advantages of SHPPs based on the DFM is that the regulation of the generator is carried out at the expense of transformation of not the whole, but only a part of electrical power of the generator (Shakaryan, 1984).

5. Inductor generators

Recently, inductor generators have found wide application in hydroenergetics. An inductor generator is a variety of a synchronous generator and has all its advantages: the strong relation between the generator frequency and the rotational speed, the possibility of generating reactive power at operating paralelly with the network, the possibility of regulating the active power by changing the current of the excitation winding at operating on an autonomous load or a small power network.

The structural differences of the inductor generator from the traditional synchronous generator are the rotor without winding and the disposition of the excitation winding on the stator, ensuring the simplicity and reliability of the structure. The toothed rotor without winding of the inductor generator is structurally simpler than the rotor of the induction generator. The excitation winding is located on the stator in the same slots as is the three-phase winding of the stator. This complicates the stator structure a little. Apart from that, there is no need for a counting-contact supply system at the excitation winding (Vol'dek, 1978; electrotermosvar, 2017; ao-electromash, 2017).

The main advantage of the inductor generator is the magnetic reduction of the rotational speed which allows to bring the rotational speed of the generator into agreement with that of the turbine without using an enhancing mechanical transmission – a multiplier.

The main disadvantage of an inductor generator is its low values of efficiency.

Conclusions

1. The possibility of generating reactive power, the case of regulating the voltage at operating on an autonomous load, the strong regulation between the generator frequency and the rotational speed, the high efficiency allow to use the synchronous generators in the whole range of the SHPP powers.
2. External damper system improves the operation mode of the synchronous generator, decreases the load of the internal damper system during continuous operation, lets generator operate at overloads.
3. Despite the limited possibilities of regulation, increased power losses, induction generators are used in SHPPs due to simplicity of their structure, maintenance, high reliability and low cost. In connection with difficulties of complete automation of the whole system with an induction generator they are primarily used at operating in the autonomous mode.
4. Application of fundamentally new generator complexes on the basis of double fed machines gives an opportunity to quickly change and regulate the parameters of the generated active and reactive powers allowing to obtain good dynamic parameters of the hydroset system because of small transient processes in the system of regulation.
5. The inductor generator which is a variety of synchronous generators has all its advantages, as well as it can ensure the magnetic reduction of the rotational speed. The low values of efficiency of the inductor generator determine the expedience of its application in small power hydrosystems.
6. The final selection of a generator for SHPPs is carried out considering the turbine power and rotational speed (the head and consumption of water) the technical and economic as well as construction and installation indices of the complex.

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MAŽOJOJE HIDROENERGETIKOJE NAUDOJAMŲ ELEKTROMECHANINIŲ JĖGOS TRANSFORMATORIŲ ANALIZĖ

M. Saghatelyan, M. Meišutovič-Akhtarieva

Santrauka

Šiuo metu Armėnijoje nesraunių upių hidrauliniai ištekliai sudaro galimybes gana veiksmingai spręsti elektros energijos tiekimo mažiesiems vartotojams problemą. Mažų hidrojėgainių sukurtos elektros energijos savikaina yra pati žemiausia, lyginant su kitų atsinaujinančių ir tradicinių energijos šaltinių sukuriamos energijos savikaina. Statant mažąsias jėgaines, skirtingai nei galingas elektrines, ekologinės žalos (žemių užliejimas, žuvininkystės ūkio griovimas, vietinių klimato sąlygų pusiausvyros pokyčiai ir t. t.) praktiškai nebūna. Šiame darbe svarstomi skirtingo pobūdžio elektros generatorių naudojimo mažojoje hidroenergetikoje klausimai. Pristatomi svarbiausi pranašumai, trūkumai, taip pat rekomendacijos, kaip naudoti elektros generatorius mažose elektros jėgainėse. Pristatoma sukurta sinchroninio hidroagregato išorinė slopinimo sistema.

Reikšminiai žodžiai: hidrogeneratorius, sinchroninis generatorius, indukcinis generatorius, dvigubojo padavimo mašina, induktorinis elektros generatorius.