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COMPENSATION OF REACTIVE POWER OF ASYNCHRONOUS GENERATORS AT SMALL HYDRO POWER STATIONS

Conditions for reactive power compensation, consumed by asynchronous generators of small hydropower stations fro electric network are considered .As the source of reactive power at small stations non-regulated capacitor banks can be used. Their optimum power is determined proceeding from the conditions of operation of the small hydro-station and electric network.

Keywords: *hydropower station, asynchronous generator, reactive power, compensation*

Introduction

Small hydroelectric power stations occupy a certain place in the energy balance of the country. Small hydroelectric power stations improve water supply of settlements, they are an important element of the system intended for creation of safe and favorable environment, as well as provide positive social impact. However, the pace of development of small hydropower stations nowadays is constrained by several economic and technical factors.

One of these factors is the type of generators installed at small hydroelectric power stations. They may be either synchronous or asynchronous machines. In a number of countries asynchronous generators(AG) are widely used for conversion of energy in installations of renewable power(especially wind power). Experience shows that for hydroelectric power stations with small installed capacity they have significant advantages over synchronous generators. This is due primarily to low cost, simplicity of construction and operation under normal conditions, resistance to external accidents, significant resource. But these generators have several disadvantages: inability to regulate voltage and reactive power consumption, emergence of active power fluctuations while rotor sliding, reactive power load surge during the start-up of the unit, the negative impact of which on the electrical distribution network is significantly increased with the increase of single power u.

This paper is devoted to investigation of operation modes of small hydropower stations operations with (AG) by reactive power in distributive networks.

Operation conditions of small hydroelectric power stations equipped with asynchronous generators in distributive networks

Two operation modes of asynchronous generators installed at electric power stations are possible – autonomous mode, when generators directly produce load, and parallel operation mode, when generators supply load in electric energy system...

For AG operating in an isolated from the system, power station a number of drawbacks are inherent. The presence of reactive power sources (batteries of static capacitors (BSC) or synchronous machines), needed for self-excitation of AG, increases the cost of electric part of hydroelectric power station. Voltage on the terminals of the generator with capacitor excitation depends on the load and speed of rotor rotation, which requires the application of automatic system of power regulation of BSC. In case of considerable inductive component of the load the capacitance of BSC needed for self-excitation of AG, increases. While operation for the load with a high power factor (cosφ = 0,9-0,98) the limit of efficient power of AG in autonomous mode is not higher than 15-20 kVA [1-3]. However, in present due to improvement of the quality and relative decrease of BSC cost , as well as control facilities the above - mentioned limit can be significantly expanded.

In case of AG operation in parallel with the grid their drawbacks associated with the use of condenser excitation, turn out to be minor, since provision and maintenance of conditions generator self excitation is not compulsory, and reactive power needed for creation of rotating field can be obtained directly from electrical network. In this situation the consumption of reactive power from electrical network for AG corresponds to its consumption in the mode of the motor. The advantages of applying AG also may include the lack of equipment needed for regulation of rotation speed of the hydroturbine. In this case, unlike the autonomous operation of AG, the speed of its rotor does not influence the speed of rotation of magnetic field of the rotor, and hence the frequency of current and voltage on the terminals of the generator. On the other hand, the lack of automation facilities of speed regulation on small hydropower stations with AG is predetermined by the fact that variations of power system load does not affect the operation of AG. The control of small hydroelectric power station operation is simplified due to lack of the need to regulate voltage on the terminals of AG, since the voltage, taking into account great power of the system, is set by the electric network.

AGs in case of parallel operation with the system do not require synchronization, that increases their manoeuvrability. At the moment of AG connection to the system with the speed of rotor rotation within 10% relatively synchronous one, AG influence on the mode of system operation is not considerable . After connection in most cases new value of rotor speed is set aperiodically, which is determined by the ratio of turbine moments and electric machine moments. Thus, active power fluctuations in the power system practically do not arise.

Small hydroelectric power stations with AG, operating in parallel with the system, are far less expansive compared with HES with synchronous generators [1]. They are economic efficient, even if they are completely automated [4], since they do not used such systems as speed turbine regulator, field killing unit, synchronization device and a number of protective units required for the normal operation of synchronous generator. The exploitation of small hydropower stations becomes easier and complete automation of the process is possible [4].

Providing excitation of autonomous asynchronous generators

As we know [2, 6], to ensure the generator mode of operation of its asynchronous machine it must be connected to AC electrical network and rotate with the help of corresponding prime mover (for example, turbine) at speed n, which exceeds n synchronous. In this case, the machine obtains negative sliding s, that is, the speed of the rotor field rotation exceeds the speed of the stator field rotation. The active component I_2 of the rotor current (Fig. 1), proportional to sliding, will be negative, that would change the direction of the active component of stator winding I current and will correspond to active power generation into the system [6]

$$\dot{I}_2 = \frac{s E_2 r_2}{r_2^2 + s^2 x_{\sigma 2}^2} - j\frac{s^2 E_2 x_{\sigma 2}}{r_2^2 + s^2 x_{\sigma 2}^2} = I_{2a} - jI_{2p}, \tag{1}$$

where s – sliding of asynchronous machine rotor; E_2 – module of secondary electromotive force (e.m.f.) of the machine; r_2, $x_{\sigma 2}$ active and reactive component of the rotor resistance circuit in equivalent circuit ; I_{2a}, I_{2p} – active and reactive components of equivalent current of rotor circuit.

Direction of reactive component I_2 does not change, hence the machine, as in the mode of motor will consume reactive power from electrical network. This aspect is a significant drawback of asynchronous generators, as compared with synchronous generators. It should also be taken into account the fact that if for the synchronous generator excitation power does not exceed 1% of the nominal power of the generator, then for AG this value reaches 70-100%. However, in case of asynchronous generator it is a reactive power, which may be partially or fully produced by capacitor unit or synchronous generator, which operates in parallel from at small hydropower station.

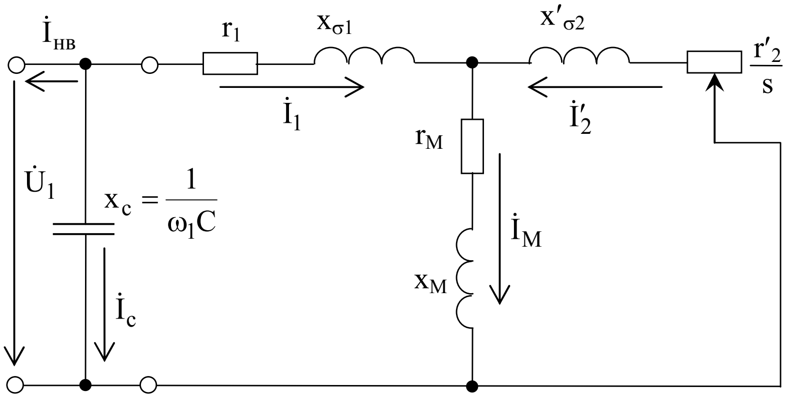

Fig. 1. Induction generator Equivalent circuit of asynchronous generator with capacitor excitation

Considering the compensation of consumption of reactive power by asynchronous generators, we should consider separately two problems: provision of favorable conditions of self-excitation for AG, which operate autonomously, and compensation of reactive consumption of AG which operate in parallel with the system to improve the efficiency of its operation by reducing the consumption of reactive power from the network.

In the first case, the necessary capacity C (hence, and installed capacity Q) of the battery of static capacitors is greater. To provide the conditions of self-excitation for AG it is necessary that the remaining e.m.f of the machine, induced by the current I=I at the expense of residual magnetization of the rotor be sufficient to create capacitive current, which would lead to increase e.m.f. of stator winding machine,i.e.

$$\begin{aligned} &\dot{I}_M\left(x_{\sigma1}+x_{i.n}\right) > \dot{I}_C x_c, \\ &\dot{I}_M = \dot{I}_C, \end{aligned} \tag{2}$$

where x – inductive resistance of non-saturated magnetic system of AG. The transient process of self-excitation is over when due to saturation of magnetic system resistance X decreases as compared with X so that

$$\dot{I}_C\left(x_{\sigma1}+x_{M}\right) = \dot{I}_C x_c. \tag{3}$$

Consequently, BSC capacity needed to provide the AG excitation , operating autonomously for the load:

$$C = \frac{1}{\omega_1\,(x_{\sigma1}+x_M)}. \tag{4}$$

Another important problem related to excitation of autonomous AG, is to provide the nominal voltage at their terminals in case of active- inductive load. In general, BSC power needed for voltage regulation can be determined:

$$Q_c = \frac{U_c^2}{X_c} = Q_g + Q_n = P_g\,tg\varphi_g + P_n\,tg\varphi_n, \tag{5}$$

where U – module of linear voltage at the terminals of capacitor installation which is determined by the voltage at the terminals of AG ($U_c = U_g$); P_g, P_n – nominal active powers of the generator and its load, which, ignoring losses in the capacitor unit, can be considered equal: $P_g = P_n = P_{nom}$.

Proceeding from (5), capacitance is defined in the following way:

$$C = \frac{P_{nom}\,(tg\,\varphi_g + tg\,\varphi_n)}{\omega_1\,U_{g.nom}^2} \tag{6}$$

Therefore, to determine the power the capacitor unit, which will provide excitement AG excitation, operating autonomously, it is necessary to use larger of the units determined in (4) and (6).

Compensation of reactive power of asynchronous generators

At modern small hydropower stations asynchronous generators are often used often in the mode of parallel operation with the system. Proceeding from this, there is no need to provide their self-excitation, as well as to regulate voltage by means of correction of BSC power, since the voltage of the generator is set by the system.

However, there remains the problem of AG reactive power compensation, as obtaining of reactive power from electric system results in increase of operating costs. To solve this problem, as mentioned above, BSC or synchronous generators are used, which are installed at the station. At the consumption of reactive power generator induction affect his Constructive parameter and operation modes influence the level of consumption of reactive power by asynchronous generators.

The structure of consumption of reactive power by asynchronous generator is the following next. The greatest power is used for creation of basic magnetic field of the machine $Q_M = 3I_M^2 x_M$. To create leakage fields of primary circuit of the machine power Q is spent $q_1 = 3I_1^2 x_{\sigma 1}$, and to create secondary leakage fields – power $q_2 = 3I_2'^2 x'_{\sigma 2}$ [6]. Total reactive power of AG consumption is determined

$$Q_1 = Q_M + q_1 + q_2 = P_g \, tg\varphi_g \,. \tag{7}$$

Installed capacity of BSC must be chosen so as to compensate the consumption of AG Q1, if the usage of excessive reactive power to supply the external customers on a commercial basis is not planned. Consequently, the necessary capacity of BSC is comparatively less with (6).

Most often, small hydroelectric power stations operate in the mode of production of constant power over a long period of time, or in the mode of periodic connections at constant power during periods of time corresponding to maximum load of the power system. Accordingly, AG being the part of the energy system have relatively stable consumption of reactive power. Consequently, the installation of non-regulated BSC of required capacity provides their operation during the whole term of exploitation. Economic power of BSC for the case of exploitation of AG in modes that are close to nominal can be defined quite simply

$$Q_{КУ} = Q_{Г.ном} = P_{Г.ном} \, tg\varphi_{Г.ном} \,. \tag{8}$$

If used as generators of serial asynchronous motors the power is 30-90% of the nominal power of the generator, depending on its design parameters.

However, often during the design of electric part of small hydroelectric power station for creation the reserve of active power of generators in order to prevent overheating and prolongation of exploitation term the generators with overrated(up to 30-50%) nominal power are chosen . The generators operate in modes that differ from the nominal mode. This is reflected in increased consumption of reactive power and leads on the one hand, to the increase of needed installed capacity of BSC and on the other – to abnormal loading of AG with reactive current. The increase of reactive power can be explained by the fact that the operation of AG with reduced capacity is connected with the reduced, relatively to the nominal, speed of rotor rotation-N and rotor sliding SS. Reduction of sliding proceeding from (1), leads to reduction of secondary current I2, mainly at the expense of reactive component:

$$I_{2p} = \frac{E_2 \, x_{\sigma 2}}{\dfrac{r_2^2}{s^2} + x_{\sigma 2}^2} < I_{2р.ном} \,.$$

Taking into account the ratio between secondary current I and the moment on the shaft of the generator M[6]

$$M \cong \Phi I_2 \;, \tag{9}$$

reduction of the rotor current I leads to increase magnetic flux of generator *F* that, through saturation magnetic circuit machines leads to a substantial increase in current magnetization *M I*, and as a consequence, greater consumption of reactive power, according to (7).

Obviously, underloaded AG is characterized by the moment on rotor shaft , less than nominal, but taking into account that secondary current I_2 decreases faster than M, the conclusion, concerning the increase of Q_1 for underloaded generators is valid.

To confirm the above mentioned the field experiment was conducted with asynchronous machine, operating in generator mode at a small power station. Nominal power of machine $P_G.nom$ = 132 kWt, nominal speed in generation mode n_{2n} = 770 rpm, rated by sliding S = 2.66%, the number of pairs of poles of stator winding-4 , efficiency η=0.932, power factor cos . = 0,86. For the given unit, changing the angle of opening of directing apparatus of drive turbine, the active power changed and reactive consumption was fixed. Results of measurements are given in Table. 1.

Table 1

The results of the experiment with determination of reactive consumption of AG

W_G , kW	Q_G, kVArh	cos φ, v.o.	W_P / $P_{G.nom}$, v.o.	Q_G / Q $_{G.nom}$, v.o.
2,12	60	0,04	0,02	0,77
9,3	61,4	0,15	0,07	0,79
16,5	62,4	0,26	0,13	0,80
24	63,9	0,35	0,18	0,82
39	66,3	0,51	0,30	0,85
46	68	0,56	0,35	0,87
52,1	69	0,60	0,39	0,88
63,2	71,7	0,66	0,48	0,92
69,9	72,6	0,69	0,53	0,93
71,5	73,5	0,70	0,54	0,94
73,5	73,9	0,71	0,56	0,95
73,6	74	0,71	0,56	0,95

The results presented in Table 1, show that under the load of generator within 56% of the nominal power its reactive consumption is 95% of the nominal. Consequently, in cases of exploitation of constantly underloaded generator the power of BSC is considerably overestimated. In this case the installation instead of the given generator the asynchronous generator (AG) with identical cos. and lower rated power would allow to reduce the needed installed power of BSC by 10-25%.

In addition to loading level, significant impact on the consumption of reactive power of AG, supplying power in electric system, has the level of voltage on-the terminals of stator windings. Taking into account that the value of basic magnetic flux *F* primary module is proportional to the modulus of primary voltage U_1 [6], increase of the latter by the value greater than the nominal leads to the increase of *F*. As it was noted above, I nonlinearly grows, and, consequently, Q_G increases, and stator winding of AG is reloaded by the reactive power. However, the voltage *U* reduction below the nominal value in case of loading of asynchronous generator close to the nominal power reduces the basic flux *F*, and Q_G of the machine, increases, according to (9), secondary current I2,that could lead to overheating of rotor winding. However, for systematically underloaded AG voltage U_1 reduction to the level of 0,95 *U* rooms can be considered as the method of reduction of the reactive power consumption, but in the case coupling transformer of hydropower station with the system should have the facilities to regulate the voltage .

The additional method of reduction of reactive power consumption for significantly underloaded AG (P_g = 0,3-0,5), according to [6] is to change connection of its stator winding from the "triangle"to the "star". This leads to reduction of phase voltage U_1 times $\sqrt{3}$, basic flux *F* – times

$\sqrt{3}$, current I_M - 2-2,5 times. According to (6) reactive consumption decreases and power factor of the generator increases. In the majority of cases, at the expense of I reduction the reactive component I_1 decreases and increases efficiency of machine increases. But the expediency of such measure for the given AG should be determined experimentally.

The suggested methods of limitation of reactive power consumption of AG allow to solve the problem of improvement of their technical-economic parameters during the operation of small hydropower stations. However, greater efficiency can be obtained at the stage of design of electrical part of small hydroelectric power station, selecting basic equipment and determining its design parameters, taking into account their interaction.

Conclusions

1. In case of appropriate selection of design parameters of electric part, in particular, compensation installations, of small hydropower stations with asynchronous generators high level of efficiency of operation is provided, electric parameters of asynchronous generators in normal modes are not inferior than the parameters of synchronous generators.
2. Reactive power consumed by AG from the network does not greatly depend on its active load, that is why unregulated capacitor banks can be used as the source of reactive power at small hydropower stations .Their optimum capacity is determined proceeding from conditions of combined operation of small hydro power station and distributive network.

REFERENCES

1. Златковский А.П. Электрооборудование сельских электрических установок. – М.: Государственное издательство сельскохозяйственной литературы, 1953. – 446 с.
2. Электрические машины: асинхронные машины / Радин В.И., Брускин Д.Э., Зорохович А.Е.: Под ред. И.П. Копылова. – М.: Высшая школа, 1988. – 328 с.
3. Костенко М.П. Электрические машины. Ч. 2. – М.: Высшая школа, 1965. – 704 с.
4. Лежнюк П.Д., Кулик В.В., Нікіторович О.В. Підвищення ефективності експлуатації малих ГЕС засобами автоматичного керування // Гідроенергетика України. – 2007. – № 3. – С. 38 – 42.
5. Петрушин В.С. Асинхронні двигуни: раціональний підхід // Електротема. – 2004. – № 24.
6. Вольдек А.И. Электрические машины. – Л.: Энергия, 1978. – 832 с.

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