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TRANSMISSION OF DC-VOLTAGE ENERGY FROM MAGNETOHYDRODYNAMIC GENERATORS INTO AN ELECTRIC POWER NETWORK

by

Z. Badzinski and A. Kordus

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TRANSMISSION OF DC-VOLTAGE ENERGY FROM MAGNETOHYDRODYNAMIC GENERATORS INTO AN ELECTRIC POWER NETWORK

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Summary

This article discusses the possibilities of changing electrical DC-energy obtained in MHD (magnetohydrodynamic) generators with Hall, Montardy and Faraday connection systems into tri-phase AC energy. It presents diagrams of inverters built from thyristors and their control and safety principles. It gives the results of calculating the basic electrical parameters of inverters working with the MHD generators adopted.

1. Introduction

Working experimental MHD generators are sources of DC electrical energy. The transmission of energy from these generators into a tri-phase network of AC current requires its transformation.

Because of the great current value induced in MHD generators it is impossible to use electromachine systems, because there are great commutator difficulties, and, in addition, the power limit of DC motors is too small for the tapping of power from MHD generators.

The only method of transmitting electric power from MHD generators to a tri-phase network is through inverters. The electromagnetic network, with which the inverters will work, is also fed by synchronous generators. Since this is a sufficient condition for the working of inverters network-excited along with a network, and it will thus be more advisable to use network-excited inverters, instead of more expensive and more complicated self-excited inverters.

Here inverters with mercury valves or semiconductive controlled diodes, called thyristors can be used. The most favorable inverters are those built from thyristors because of their small dimensions and great efficiency. By inserting an inverter in a transformer tank it is possible to improve the conditions for cooling thyristors and to reduce the temperature variability of their operation. Such a method permits the building of an aerial inverter station.

The station, equipped with mercury valves, must also consist of a chamber of valves and a number of auxiliary locations, and is therefore highly complex, and for this reason only inverter systems built from thyristors have been further discussed.

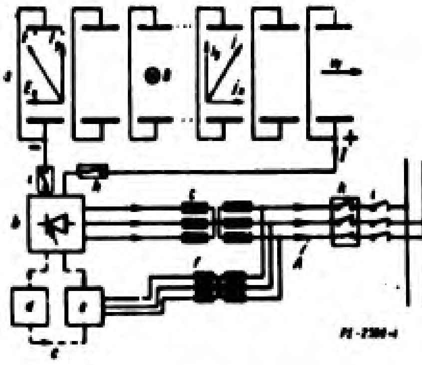

Fig. 1. MHD generator in a Hall system; inversion and transmission of electric energy into a tri-phase circuit.
a – MHD generator; b – thyristor inverter (according to Fig. 5); c – transformer; d – safety system (according to Fig. 6); e – control, regulation and screen-blockade system; f – auxiliary transformer; g – bus-bars; h – anode switch; i – cathode switch; j, j_x, j_y – current density in plasma, accidental, longitudinal and transverse, respectively; k – tri-phase switch; ℓ – isolator; w – speed of plasma in a generator channel; A – energy transmitted to tri-phase network; B – inductance; C – control pulse; E, E_x, E_y – electromotive force, incidental, longitudinal and transverse, respectively; I – generator current.

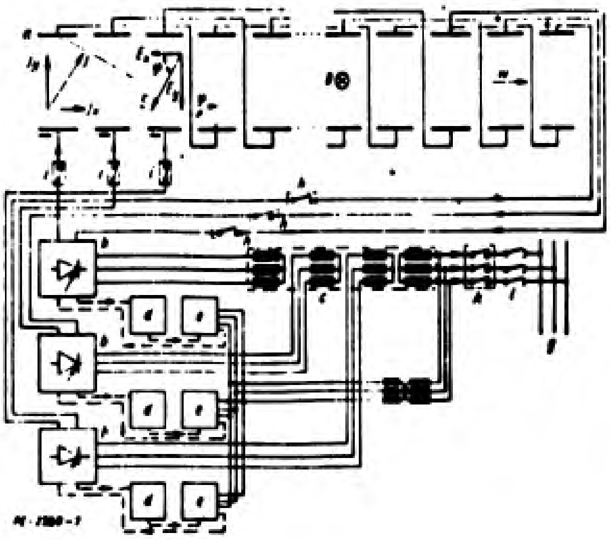

Fig. 2. MHD generator in the Montardy arrangement with three loading circuits; inversion and transmission of electrical energy into a tri-phase network. ϕ – Hall angle; remaining designations as in Fig. 1.

2. Inversion Systems for Various Loading Configurations of Electrodes

The simplest system of MHD generator electrodes is a system consisting of two continuous electrodes. This system can be used only with small inductance values (magnetic induction), because its rise causes an increase in the Hall effect and then the formation of component current along the axis of the channel and eddy currents.

A reduction in the effect of this phenomenon can be obtained by the segmentation of electrodes and their corresponding connection (Hall, Montardy and Faraday systems).

2.1. Tapping of Energy from a Generator in a Hall System

With high inductance and the use of inert gases it is advisable to connect the electrodes according to the Hall system. In this system all opposite electrodes are coherent pairs, and the load is connected between the first and last pair of electrodes (Fig. 1a). Because Hall phenomena appear in the generator channel, the incidental vector of induced electromotive force is the sum of the vectors of electromotive forces E_x (emf Hall – appearing along channel) and E_y (emf diagonal to channel). Magnitudes designated by asterisks pertain to the coordinate system moving at rate w. The generator is connected by anode switch h and cathode switch i with inverter b. The inverter is made in a two-directional arrangement with thyristor valves. The control, regulation and network-blockade system e of the inverter is fed from an auxiliary transformer f. The network blockade of the control system in case of disturbances in the operation of the inverter is controlled by a system of internal safeguards d of the inverter. Energy is transmitted from the inverter to a tri-phase network g through transformer c, circuit breaker k and isolator ℓ. Tapping of energy and its inversion is the simplest in this system, but the electric powers obtained are smaller than in the generator systems described below.

2.2. Tapping of Energy from a Generator in a Montardy Arrangement

An MHD generator in a Montardy arrangement can be loaded by one or several receivers. Figure 2 presents a diagram of such a generator with three loading circuits.

Schemes of systems coupling the generator with a tri-phase network are similar to the scheme discussed in Paragraph 2.1. The transformer of this system must have as many primary windings as there are pairs of output terminals of the MHD generator (thus, as many inverters of the system as there are). In this way the summation of electrical energy obtained at the output pairs of the generator terminals is realized magnetically.

2.3. Tapping of Energy from a Generator with Sectional Electrodes – Faraday System (Fig. 3)

The Faraday system, based on the segmentation of electrodes and loading of every section by a special impedance, eliminates to a considerable degree the effect of the Hall phenomenon. Practically speaking, it gives the greatest power of all the above-described electrode-connection systems. In this system every section works with one inverter and one primary transformer winding. Wanting to load every section at will, we must provide the inverter with individual control and regulation systems.

3. Thyristor Dual-Direction Inverter System

Thyristors are valves with especially favorable properties. They differ from other electric valves in their low power utilization in the control circuit, small voltage drop and high rate of action.

If a voltage supplied to a thyristor is smaller in the direction of conductivity than the voltage of the flashover U_p (Fig. 4), then the thyristor is in a valve state. When the supplied voltage exceeds value U_p, then the thyristor is converted into a conduction state characterized by a high conduction current (up to 600 Amp) and a small voltage drop on the thyristor (about 1.5 V). By supplying a potential amounting to 3-5 V to the control electrode a reduction in the flashover voltage is obtained.

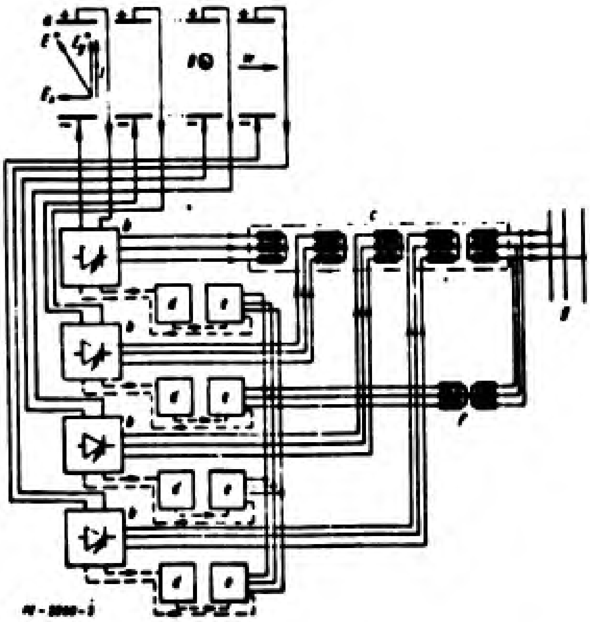

Fig. 3. An MHD generator in a Farady system; inversion and transmission of electric energy into a tri-phase network; designation the same as in Fig. 1.

In this way by changing the current of the thyristor base regulation of its working state is obtained. As soon as it is switched over into a state of conduction the thyristor is no longer under the effect of the control electrode.

When the thyristor is polarized in the valve direction in the range of voltage from 0 to U_{max} the thyristor exerts great resistance. The exceeding of value U_{max} causes a violent current rise, which may lead to the destruction of the thyristor.

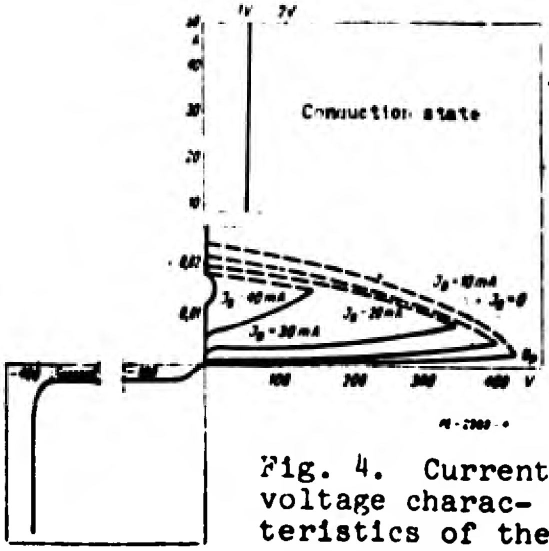

Fig. 4. Current-voltage characteristics of the thyristor: U_p – Flashover voltage; I_p – conduction current; I_B – current of the base; U_{max} – maximum safe reverse voltage.

The possibility of controlling a thyristor allows us to use it in inverter systems, in which considerable delay in the ignition of valves is essential.

Figure 5 presents a dual-direction bridge inverter. Because of the relatively low rated values of currents and voltages of thyristors presently produced this must be a multiple system. Each of the three branches of the bridge (Fig. 5) thus has $n = 4$ thyristors connected in series and $m = 3$ thyristors connected in parallel. The uniform voltage distribution on the series connected thyristors ensure resistors connected to them in parallel. A careful selection of thyristors and of remaining inverter elements is sufficient to insure uniform dispersion of current for the commutation of a pair of inverter valves.

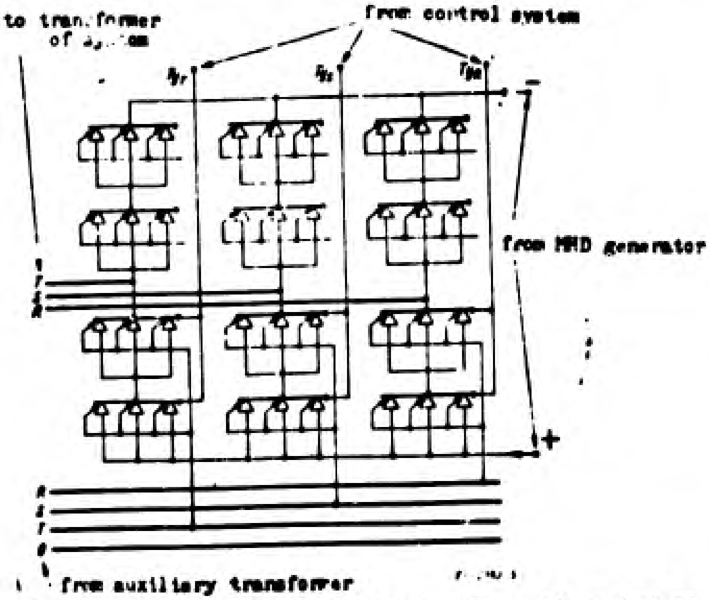

Fig. 5. Wiring diagram of a thyristor tri-phase bridge inverter.

In the composition of each of the branches two groups of valves are included. Each of the valve groups transmits within a time period corresponding to angle $2\pi/p = 120°$. ($p = 3$ – the number of inverter system phases.)

4. Principles of Controlling and Regulating Inverter Systems

To obtain the most optimum possible (from the viewpoint of physical parameters of an MHD generator channel) method of loading each pair of output terminals of an MHD generator, every inverter working with this generator requires the use of a separate control system.

By changing the moment of ignition of the thyristor (or group of thyristors in a multiple inverter) it is possible to regulate the inverter load, and thus also the MHD generator load. The requirements laid down for the control and regulation system of inverter thyristors arise from the ignition characteristics of the thyristor and the properties of the inverter system [2].

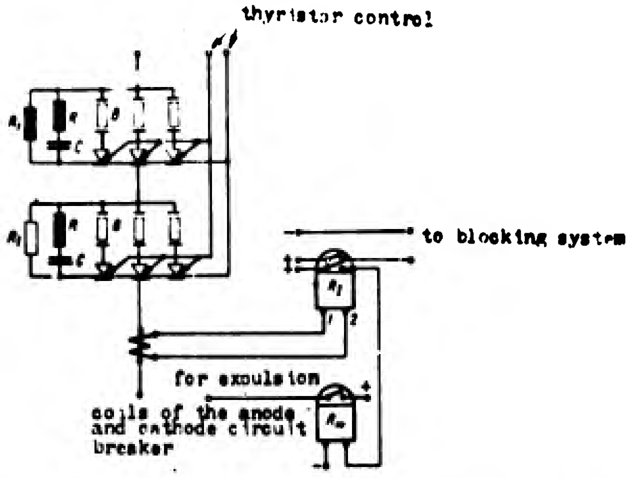

Fig. 6. System of internal safeguards of the group of valves.
B – Safety fuses; R – overvoltage protection resistors; R_1 – resistor ensuring uniform voltage distribution in the thyristors; R_I – overcurrent relay; R_W – executive relay.

The ignition system should fulfill the following requirements:

– the value of the control current must ensure reliable ignition of the thyristor, but must be maintained within permissible values;

– at the time that voltage in the reverse direction appears on the thyristor, no control current is desired;

– after switching the thyristor to the conduction state it is not subject to the effect of the control electrode and the flow through of control current is not necessary;

– time of flow through of the control current should be long enough to ensure ignition of the thyristor;

– the control current should appear at the same phase angle in every branch of the inverter, which ensures uniform loading of all the valves (or groups of valves in a multiple inverter system);

– for a tri-phase bridge system (Fig. 5) control currents of thyristors (or group of thyristors) of one branch must be shifted by 180° with respect to each other;

– the control system should have input circuits for the introduction of additional connections;

– ignition systems of inverter thyristors should be controlled from one control system;

– the pitch of the front of the control pulse should be as great as possible to ensure high control precision.

Many control systems, built mainly from transistors and thyristors, conform to these requirements.

5. Systems of Safeguarding Internal Inverters

The highly important problems are: protection against overvoltages and safeguarding the thyristors against the effects of short circuits.

Protection against overvoltages is normally realized by diverting the thyristor (Fig. 6) by an RC series circuit with resistance $R = 30\text{-}90\ \Omega$ and capacitance designated from the empirical formula

$$C = \frac{10 I_n}{U_n}$$

in which: C – capacitor capacitance, in μF; I_n – rated current of thyristor, in A; and U_n – rated voltage of thyristor, in V.

The safeguarding of thyristors from the effects of short circuits provide cartridge fuses connected in series with the thyristors. The fuse must fulfill the following requirements:

– the rated current of the safety fuse should be as close as possible to the effective value of the current flowing through the thyristor at the rated loading of the inverter;

– rated voltage of the safety fuse should not be higher than the voltage of the rated thyristor;

– overvoltages, when switching short circuits through the safety fuse, appear at the arc time of the safety fuse and should be lower than the voltages of the limit thyristor;

– the current-time characteristics of the thyristor safety fuse should be below the overload characteristics of the thyristor;

– the parameter I^2t of the fuse, characterizing its boundary capacity of energy cummulation for the entire time of the fuse's action, should be smaller than the analogous parameter of the protected thyristor;

- the pulse of the current passed through the cartridge must be placed within the endurance boundaries of the thyristor.

Additional insurance against the effects of short circuits and overloads can be realized by a current switcher connected with the over-current relay R_I. At the moment the anode current rises above the rated value the relay R_I will close its contacts. The blockade circuit remains closed, which will block the operation of the control system and as a result interrupt the operation of the inverter.

Another pair of contacts of the over-current relay R_I will close the circuit of relay R_W, which causes the feeding of a signal for the opening of anode and cathode circuit breakers. Contacts 1 and 2 of relay R_I must be connected with all six current switchers of all six groups of valves of the tri-phase bridge inverter.

A uniform distribution of voltages at the parallel-connected thyristors is ensured by resistors R_1 with a resistance on the order of several tens of kilo-ohms each.

In order to avoid overmeasuring of the inverter, it is necessary to ensure a sequence of switching on the connectors, such that the inverter system should never find itself below the voltage of an idling MHD generator. In accordance with [6] the idling-state voltage considerably exceeds (from three times) the working voltage under load. The connection of such high voltage to thyristors must cause their penetration in the direction of conduction, even with the lack of control current. This leads to a short circuiting of the MHD generator through the low resistances of the thyristors. Because of the low thermal capacitance of thyristors their destruction by the short circuit current of an MHD generator would be very rapid.

The system of insuring against the effects of short circuits by overcurrents [Translator's Note: original text has probable misprint here] the anode and cathode disconnectors must have very short eigen working periods. From these disconnectors connections and disconnections of high rated current values, on the order of several kAmp, will be required.

6. Comparison of Proposed Solutions

For the purpose of comparing the inverter systems for three types of MHD generators calculations of the basic parameters of electric inverters which would work with these generators were made.

We have assumed that these inverters are built from thyristors of the Westinghouse CS-type with data: rated current $I_n = 580$ Amp, flashover voltage $U_n = 800$ V, maximum safe reverse voltage $U_w = 1250$ V.

It has been assumed that each of the generators with 30 sections (pairs of electrodes) has a net rated electric power of P = 100 mW. It was assumed according to [3] and [4] that voltages were rated U_s and power distributions were for generators in a Montardy system with three loading circuits and for a generator in a Faraday system. On this basis rated currents I_s of generators were calculated, as well as such inverter parameters, as:

- phase voltage of primary transformer winding

$$U_{1f} = \frac{U_s\,|\cos(\alpha - \gamma)|}{\sqrt{3} \cdot 1{,}35}$$

where the angle of ignition lead is assumed in accordance with [2] as equal to 30°. This angle can be described by the formula

$$\gamma = \delta + \gamma_0$$

in which γ_0 is the phase angle corresponding of the time of reconstructing the barrier properties of the valve, and the commutation angle δ is the phase angle corresponding to delays in the increase and reduction of anode currents. The phenomenon of delay in the rise and reduction of anode currents is the result of the effect of induction reactances of the transformer and of the inverter circuits;

- the effective value of the current of a group of valves

$$I_a = 0{,}577\,I_s$$

Table 1. Compilation of basic electrical parameters of examined MHD generators and their inversion systems.

Basic electrical parameters of MHD generators and their inversion systems	MHD generator in loaded system		
	Hall's	Montardy (for 3 loading circuits, values for 1 section)	Faraday (for 30 loading circuits, and average values for one section)
Electric power of generator P mW	100	33,3	distribution according to Fig. 9, average 3.33
Rated voltage of generator U_s kV	15	8	distribution according to Fig. 9, average 1.31
Rated current of generator I_s kA	6,67	4,17	distribution according to Fig. 9, average 2.54
Primary phase voltage of transformer U_{1j} kV	5,56	2,96	distribution according to Fig. 9, average 0.475
Effective current value of group of of valve group' I_a kA	3,84	2,40	distribution according to Fig. 9, average 1.47
Effective current value of primary transformer winding I_1 kA	5,45	3,4	distribution according to Fig. 9, average 2.09
Number of parallel thyristors in the inverter branch m, No.	7	5	sec. 1 to 11, m = 4 sec. 12 to 22, m = 3 sec. 21 to 30, m = 2
Number of series thyristors in the inverter branch, n, No.	18	20	4
Total number of thyristors, No.	756	300 Σ = 900	1002
Number of anode disconnectors, No.	1	1 Σ = 3	30
Number of cathode circuit breakers, No.	1	1 Σ = 3	30

– effective current value of primary transformer winding

$$I_1 = 0{,}816\,I_s$$

– number of parallel- and series-connected thyristors in the inverter branch and total number of inverter thyristors.

The data assumed and results of calculation are presented in Table 1 and Fig. 7. Because of the assumption that the rated currents and voltages of all three load circuits of an MHD generator in a Montardy system are the same, in the fragment of Table 1 pertaining to this generator calculation results of only one load circuit are presented (with exception of the last three positions, in which the results for one and three load circuits are given).

As is evident from Fig. 7, the nonuniform distribution of voltages and currents in individual generator sections in a Faraday system compels us to use inverters of various powers for the individual sections. In the part of Table 1 pertaining to this generator average values of the calculated parameters are given.

From the viewpoint of selecting inverter systems for MHD generators the generator in the Faraday system is the most unfavorable. If the number of sections of this generator is designated by z, then this generator – for the transmission of energy into a tri-phase network – requires the use of z inverters, anode and cathode disconnectors, and z control and regulation systems. The transformer collaborating with these inverters must have z primary windings.

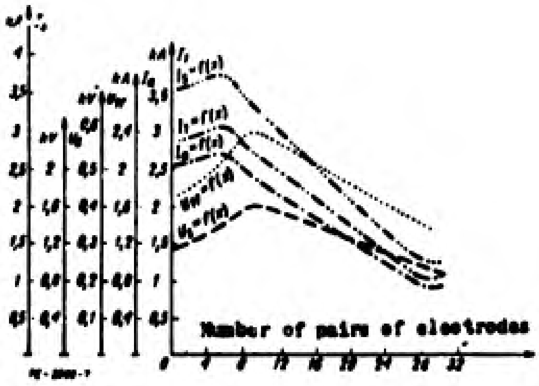

Fig. 7. Distribution of electrical parameters of an MHD generator in a Faraday system and its inverters. U_{1f} – Phase voltages of primary transformer windings; I_a – effective values of anode currents of groups of valves; I_1 – effective values of currents of primary transformer windings; I_s – currents obtained in individual sections; U_s – voltages of sections.

The generator in a Montardy system possesses a considerably smaller above-assumed z number and for this reason the number of inverters connectors, control and regulation systems and the number of primary transformer windings is relatively low.

7. Conclusions

The type of circuit in which an MHD generator works and the inductance used have a decisive effect on the configuration of generator electrodes (thus, also on the system of inverters working with the generator). When combustion products are utilized (open circuit) and low inductance is employed the Faraday system is preferable. The Hall system is especially suitable when using high inductance and inert gases (closed circuit). If we take into consideration the selection of inverters and the magnitude of the electrical energy created in an MHD generator, then the optimum solution is an MHD generator in a Montardy system.

Since MHD generators have to work with an electric energy network, the excitation frequency of the electrodes of the control inverters must therefore be closely connected with the frequency of the network powered by these inverters. This condition points, therefore, toward the necessity of using exclusively network-excited inverters in the systems discussed. A network-excited inverter, connecting the DC-current circuit with the AC-current circuit, transfers only the active power into the AC-current circuit. Passive power, needed for the AC-current circuit because of the power coefficient of the inverter which is always smaller than unity, must be delivered through the remaining sources attached to this circuit.

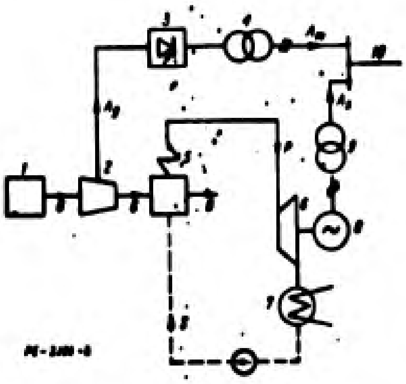

Fig. 8. Connection of an MHD generator with the conventional circuit of an electric power plant. 1 – Combustion chamber; 2 – MHD generator; 3 – thyristor network-excited inverter; 4 – inversion transformer; 5 – boiler; 6 – steam turbine; 7 – condenser; 8 – synchronous generator; 9 – transformer; 10 – electrical energy network; A_g – DC-electrical energy; A_m – transformed electrical energy; A_s – electrical energy from a synchronized generator; P – steam; S – condensates; G – ionized gas (plasma).

Current of induction nature, required for inverter operation, loads the synchronized generator, which "guides" the inverter in the AC-current circuit; this generator does simultaneously determine the voltage frequency. The necessity of the existence in the AC-current circuit of a variable EMF source, loaded by the passive power f a network-excited inverter, is no hindrance to the realization of a system with an MHD generator. MHD generators must work in close connection with the turbo units of a conventional electric power plant (combustion gases from the channel of an MHD generator must heat the boiler connected to the conventional circuit of the power plant - Fig. 8). These turbo systems as well as the electric energy network will insure feeding the inverter with passive power and will simultaneously determine the frequency of its operation.

In considering the construction of inverter systems, it is necessary to emphasize the superiority of semiconductor valves over mercury ones. According to the experiences of representatives of the Westinghouse Electric Corp. (Manchester, 1966), in the year 1971 an inverter station using thyristor valves will be about 23.5% less expensive in construction and operation in comparison with a station of similar power using mercury valves, but by the year 1976 this difference will rise to 30.5%. The area occupied by an inverter station with thyristor valves is estimated to be 20% of the area occupied by a corresponding station with mercury valves. The slight difference in efficiency of these stations (98.8% for a station with mercury valves and 98.5% for a station with semiconductor valves), because of the above mentioned advantages of thyristors, appears not to be of very great significance.

Summary

This paper discusses the possibilities of transforming DC electrical energy, produced from magnetohydrodynamic generators, connected by Hall, Montardy and Faraday systems into AC electrical energy of tri-phase current. Inverter diagrams consisting of thyristors, as well as the principles of their control and protection,

are presented. Results of calculations of the basic electrical parameters of inverters working with the assumed magnetohydrodynamic generator are given.

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ABSTRACT

(U) This article discusses the possibilities of changing electrical DC-energy obtained in MHD (magnetohydrodynamic) generators with Hall, Montardy and Faraday connection systems into tri-phase AC energy. It presents diagrams of inverters built from thyristors and their control and safety principles. It gives the results of calculating basic electrical parameters of inverters working with MHD generators adopted.