ELECTROMECHANICAL AC CONVERTER FOR REGIME CONTROL AND SHORT-CIRCUIT CURRENT LIMITATION IN THE METROPOLITAN ENERGY SYSTEMS

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AC electromechanical asynchronized machine-based converter substation is a functional equivalent for transistor power converter-based DC converter substation.

Keywords: electromechanical AC converter substation; short circuit current; electrical machinery.

Modern metropolises consume more and more electric energy

ASYNCHRONIZED ELECTROMECHANICAL FREQUENCY CONVERTER (AEMFC): APPLICATION AND DESIGN

The dense energy system of any metropolitan city is characterized by a considerable energy consumption, high generating capacities and relatively short power transmission lines of 110–500 kV voltage ratings. Both international and Russian practices confirm that the energy consumption in metropolitan cities tends to a sustainable growth.

As a result, short-circuit current (SCC) levels in 110/220 kV metropolitan grids exceed 63 kA which is more than the maximum breaking current of industry-standard circuit breakers.

The main way of the SCC limitation is the grid sectioning [1]. Moscow 220 kV grids include more than 40 sectioning points, while 110 kV — about 100 points. The grid sectioning is efficient for the SCC limitation, but reduces the power supply reliability, makes repairs more difficult and affects the flexibility of the power grid control system.

Another efficient way of the advanced SCC limitation is an electromechanical AC converter based on asynchronized devices (AEMFC), being a package unit at a common shaft of which two asynchronized units are installed [2]. In addition to the SCC limitation, such AEMFC can be used as a flexible link between two systems having different rated frequencies, or between two parts of one system with the same rated frequency.

This unit ensures the controllability of transmission lines in wide ranges as to the transmission capacity up to its reversal and permits to deaccentuate power kicks and fluctuations at transient points between two systems (or two parts of one system) so that the disturbance (for instance, due to short circuits) can be localized. Auxiliary means can be reduced as required for controlling the reac-

ASYNCHONIZED ELECTROMECHANICAL FREQUENCY CONVERTER BASED ON TWO ASYNCHONIZED MACHINES

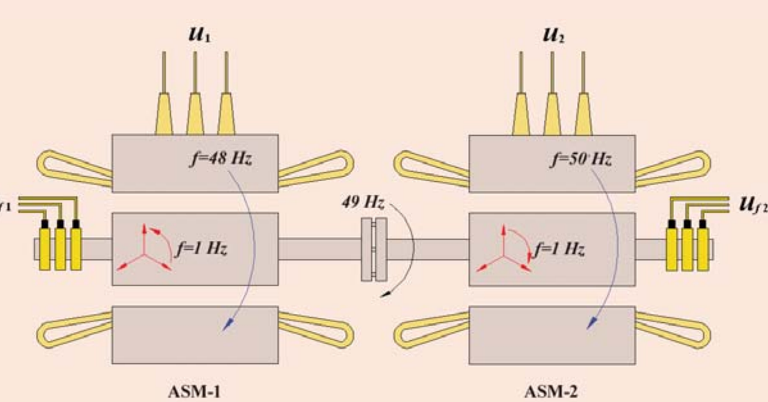


Fig. 1

INFORMATION

The Moscow energy ring is formed by high-voltage transmission lines (500 kV voltage) and a group of the most powerful substations (PS) located both within the city and in the Moscow region. The main task of these hub substations is to reduce the voltage from 500 to 220 and 110 kV and transfer it to nodal distribution substations. Electricity in the ring comes from the Volga-Kama hydroelectric power plants, Kalininskaya NPP, Kostromskaya GRES through the 750 and 500 kV lines and from the nearest power plants in the Ryazan, Tula and Kaluga regions — along 220 kV lines.

Public Joint Stock Company "Moscow United Electric Grid Company" is one of the largest distribution electric grid companies in Russia. It was formed on April 1, 2005 as a result of the section "Mosenergo". Initially called "Moscow Regional Electric Grid Company", since June 26, 2006 has the current name.

"Moscow United Electric Grid Company" has 607 high-voltage substations, 28.1 thousand transformer substations of distribution networks, 65.5 thousand km of overhead transmission lines, 71.9 thousand km of cable power lines.

By 2020, the region's energy supply system should ensure a two-fold increase in demand for electricity. The most important feature of power supply systems for megacities is a high degree of concentration of electrical and thermal capacities at CHP plants located mainly in Moscow, high interdependence of electric, thermal, hydraulic regimes, the combined nature of both electricity and heat production and their consumption.

tive power in wide ranges, including modes of the advance reactive power consumption. Moreover, the AEMFC excludes transmission of negative-sequence and zero-sequence currents, high harmonics of current and voltage from one grid to another, i.e. connected grids become electrically separated. The controlled active-power flow is possible in the switching point. In fact, the AEMFC is a complete analog of DC-link modern versions based on fully controllable power keys (IGBT-transistors).

Fig. 1 shows a principle diagram of an AEMFC incorporating two asynchronized units (ACM-1 and ACM-2).

If ACM-1 functions as a generator, ACM-2 is used as a motor. But if the power flow direction changes due to the electric unit reversibility, the first unit switches to a motor mode and the second — to a generator mode.

For instance, if one energy system (ES) is characterized by the current frequency f = 48 Hz, and the other — f = 50 Hz, then the AEMFC rotor shaft rotates with a frequency amounting to their half-sum (49 Hz). This is achieved by rotating the ACM-1 excitation field in a direction opposite to the rotor shaft rotation direction with a frequency of 1 Hz and similar to it in ACM-2 with a frequency of 1 Hz.

Thus, the AEMFC permits to "separate" energy systems 1 and 2 by frequency. In addition, ACM-1 and ACM-2 can be used to regulate each system voltage independently of each other if operating in the mode varying from supply to the advanced consumption of the reactive power.

If one system is subject to dynamic fluctuations (for instance, short circuits), they are localized in this system and not transmitted to the other, as there is no electrical link between connected systems.

ASYNCHONIZED ELECTROMECHANICAL FREQUENCY CONVERTER (AEMFC) STRUCTURAL DIAGRAM

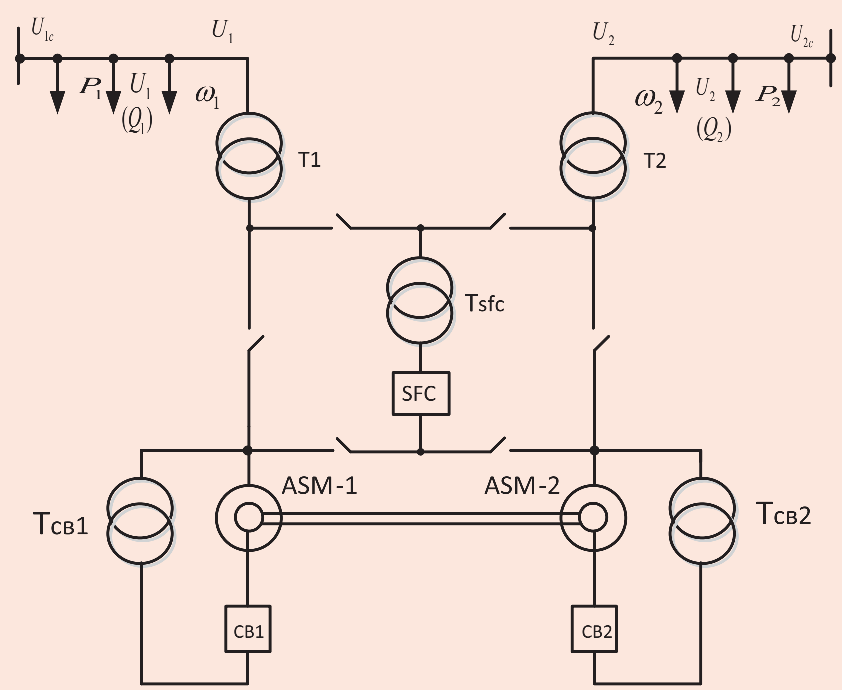


Fig. 2

COMPARISON OF AEMFC AND ACCS MAIN TECHNICAL AND ECONOMIC PERFORMANCES

Unit type	AEMFC 486/200-8	ACCS 100 MW Mogocha Substation	AEMFC 486/400-8	ACCS 200 MW
Nominal power, MW	100	100	200	200
Rated power factor	0.85	0.85	0.85	0.85
Short-term overloads	Yes	No	Yes	No
Plant footprint, m^2	736	2385	736*	4770
Unit cost, USD/kW	96	250	86	250

* The footprint is not increased since the power plant will be expanded in depth (height) to increase the power output.

Table 1

100 (200) MW AEMFC OVERALL DIMENSIONS

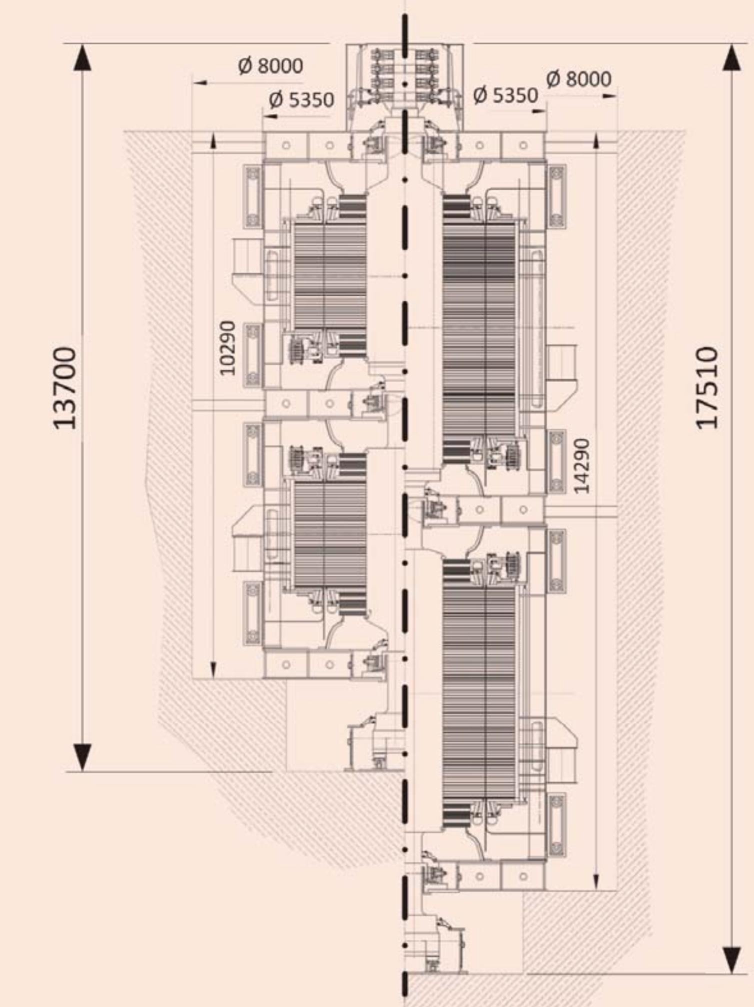


Fig. 3

When two energy areas of the same frequency are connected, the rotor rotates with a synchronous speed (or a minimum slip ratio to provide a uniform heating of energizing coils).

At present, JSC R&D Centre of FGC UES (previously VNIIE) and PJSC Power Machines (Electrosila plant) have an elaborated version of an AEMFC incorporating two units with a rated capacity of 2 x 100 MW (AEMFC 486/200-8) or 2 × 200 MW (AEMFC 486/400-8).

The AEMFC package includes the following main equipment (Fig. 2):

- packaged step-up transformer (T1, T2) — 2 pcs;
- asynchronized unit (ACM-1, ACM-2) — 2 pcs;
- energizing system (CB-1, CB-2) with an energizing transformer (Tсв1, Tсв2) — 2 pcs;
- start-up frequency converter with a transformer (or a reactor) (Tsfc) — 1 pc.

See Table 1 for technical parameters of the asynchronized unit with a capacity of 100 MW and 200 MW. Fig. 3 shows a dimension drawing of the AEMFC with a capacity of 100 MW and 200 MW. In principle, the unit can be designed for higher rated capacities (300–500 MW). The AEMFC generators can withstand double short-term current overloads. The AEMFC efficiency is lower as compared with DC-links. Its active power ascension rate is consistent with the DC-link control speed. The active power increases from zero to the rated value within 0.3 s at most.

Two AEMFC units with a capacity of 100 or 200 MW, including auxiliary equipment (two energizing systems with transformers and start-up frequency converters — see Fig. 4) can be arranged in a 46 x 16 m machine hall.

The preliminary arrangement of such system for the option "2 AEMFC x 200 MW" is shown in Fig. 5.

The AEMFC has a functional analog in the form of a DC-link, being a static device based on transistor power converters (STATKOM) [3]. See Fig. 6 for the equipment layout at the 220 kV Mogocha Substation. Overall 100 MW DC-link dimensions at the 220 kV Mogocha Substation (without step-up transformers, but including a 35 kV Gas Insulated Switchgear): 53 × 45 m = 2385m^2, which exceeds significantly the AEMFC dimensions. See Table 1 for the comparison of AEMFC and DC-link main technical and economic performances by the example of the 220 kV Mogocha Substation.

We will consider AEMFC properties in more details below.

AEMFC FOR SHORT-CIRCUIT CURRENT LIMITATION

The AEMFC efficiency for the short-circuit current limitation is demonstrated by modeling a link between two energy areas via the AEMFC as per a scheme shown in Fig. 7. Shot-current in any energy area results in zeroing of the setting $P_{set} = 0$. The unit operates at idle with a constant rotational frequency. Voltage at ACM buses of the non-affected energy area is maintained equal to the setting $U = U_{set}$.

Maximum fault-current contribution in the SC point at the 220 kV side amounts to:

- 5.6 kA for a 200 MW AEMFC;
- 2.4 kA for a 100 MW AEMFC.

See Fig. 8 for results of modeling thee-phase SC with a duration of 0.18 s at a time moment of 0 s.

STRUCTURAL DIAGRAM OF TWO 100 (200) MW AEMFCS

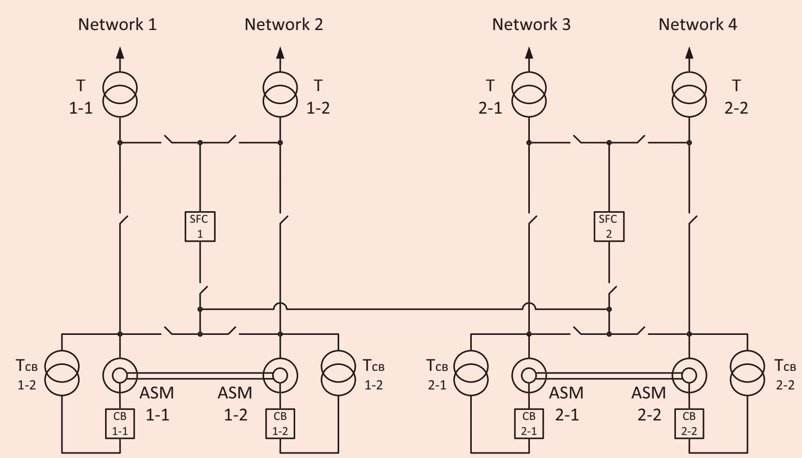


Fig. 4

CONFIGURATION OF 2 × 200 MW AEMFC

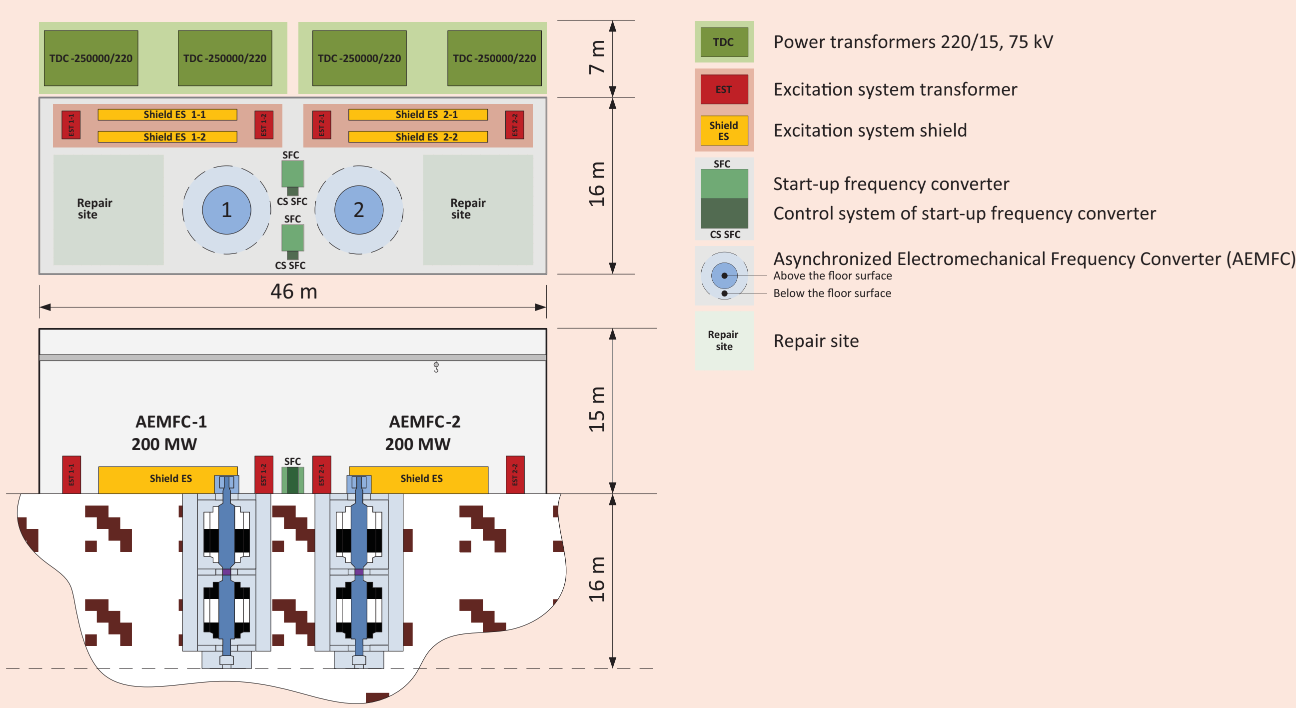


Fig. 5

CONFIGURATION OF 100 MW ACCS AT 220 KW MOGOCHA SUBSTATION

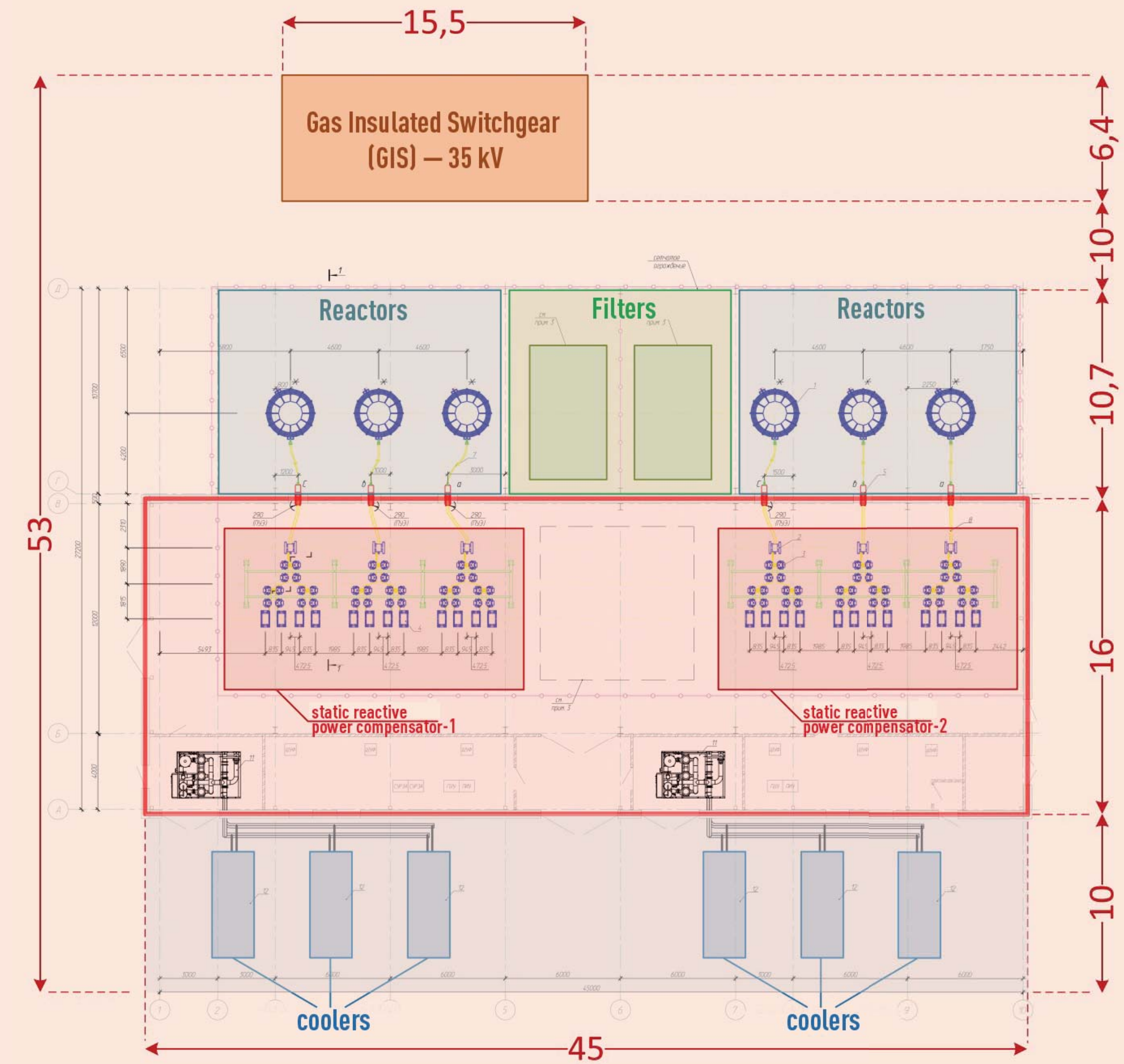


Fig. 6

AEMFC FOR VOLTAGE LEVEL REGULATION

Due to its asynchronized control philosophy, the AEMFC is suitable for the grid voltage regulation by adjusting the reactive capacity in wide ranges, including modes of the advanced reactive capacity consumption.

The AEMFC control functions are implemented by an automatic excitation controller (AEC) via four control channels (Fig. 9) enabling the adjustment of the following parameters:

- active-power flow Pл from ES-1 to ES-2 or vice versa;
- voltage U1 (reactive capacity Q1) in ES-1;

AEFMC AND ADJACENT ELECTRIC POWER SYSTEMS TO MODEL THE SHORT-CIRCUIT CURRENT LIMITATION

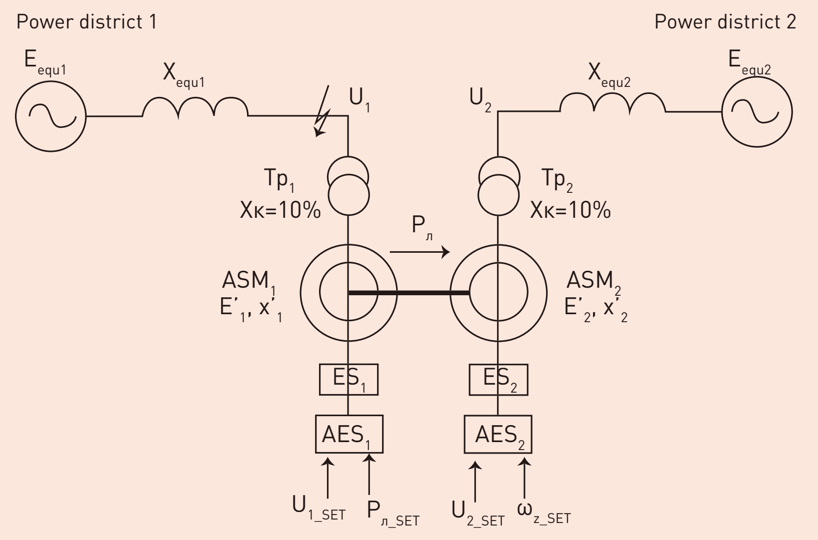


Fig. 7

- voltage U2 (reactive capacity Q2) in ES-2;
- setting of the rotor rotation frequency equaling a half-sum of frequencies in ES-1 and ES-2.

This feature permits an independent regulation of active (Fig. 10) and reactive (Fig. 11) power.

Fig. 12 shows the reactive power operating range for the 200 MW AEMFC.

AEMFC APPLIED IN THE MOSCOW ENERGY SYSTEM

Preliminary calculations made by the Moscow Regional Dispatching Office confirm that AEMFC-based solutions are efficient for newly arranged 220 kV transits in Moscow. See Fig. 13 and 14 for AEMFC proposed installation locations. See Table 2 for results of calculations.

The prospective development of the Moscow Region high-voltage grid was

CALCULATION DATA FOR AEMFC PLANT IN 220 KV GRID

№	Item	AEMFC power, MW	Short-circuit current with closed transit lines / AEMFC, kA	Current normalization	Recommendations for the plant
1	TPP 26 — SS Bitsta	2 × 200	60.6/44.7*	Yes	Yes
2	SS Gorkovskaya — SS Tsimlyanskaya	2 × 200	42.8/34.6*	Yes	Yes
3	TPP 12 — SS Presnya	2 × 200	68.5/38.1*	Yes	Yes
4	SS Magistralnaya — SS Belorusskaya	2 × 200	70.0/51.5*	Yes	Yes
5	SS Beskudnikovo — SS Grazhdanskaya	1 × 200	78.3/66.1*	Yes	No
6	TPP 20 — Kozhevnichevskaya I, II	2 × 200	77.2/48.9*	Yes	Yes
7	TPP 23 — Krasnoselskaya I, II	2 × 200	77.2/48.9*	Yes	Yes
8	TPP 23 — Krasnoselskaya 1, 2 and TPP 20 — Kozhevnichevskaya 1, 2	2 × 200 2 × 200	89.8/53.6**	Yes	Yes

* Including current inflow from AEMFC.
** Some switches need to be upgraded 40 kA to 63 kA (scheduled for 2017-2019).

Table 2

SHORT-CIRCUIT CURRENT LIMITATION RESULTS

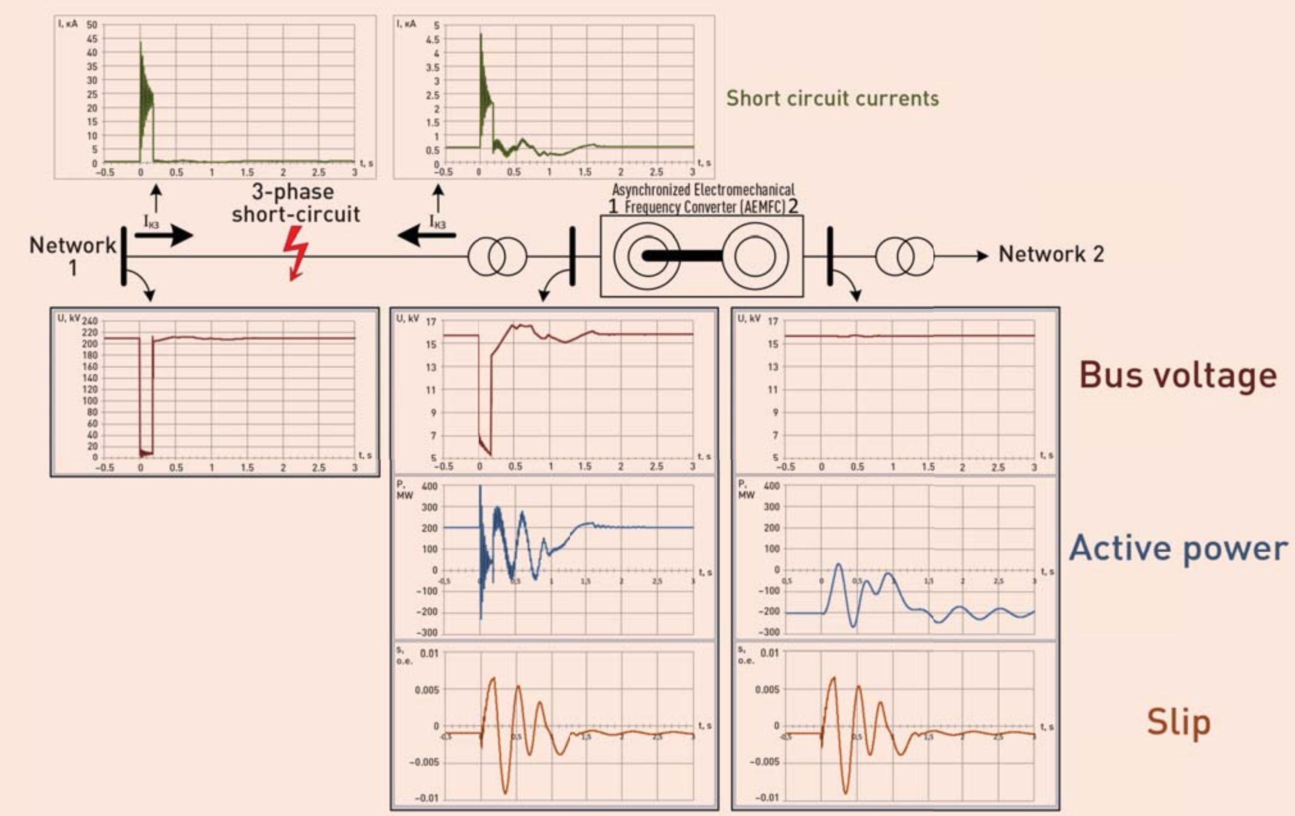


Fig. 8

analyzed when preparing "Moscow Power Sector Prospective Development Programs and Charts for 2014–2019" (approved by Moscow DepTech Order No. 01-01-14-13/14 dated 29.04.2014) and "Moscow Region Power Sector Prospective Development Programs and Charts for 2015–2019" (approved by Moscow Region Ministry of Energy Order No. 24-P dated 29.04.2014), as well as in the course of elaborating "Complex Development Program on 110 kV and Higher Power Grids in Moscow and Moscow Region for 2014–2019 and up to 2025" (Energosetproyekt, 2014, by request of OJSC "MOESK") to confirm the need for short-circuit current limitation measures at newly arranged 220 kV grids within the New Moscow area in 2020–2025 (transit of 220 kV cable lines "Nikulino — Khovanskaya — Philippovo — Lesnaya).

CONCLUSION

1. AC electromechanical asynchronized machine-based converter substation is a functional equivalent for transistor power converter-based DC converter substation showing the following main advantages as compared to the latter:
   - absence of higher harmonics;
   - admissible short-term current overload up to doubled values;
   - home-made products, high level of prefabrication, ability of PJSC Power Machines to implement batch production of main AEMFC components: asynchronized generators, excitation systems withe vector control features, start-up frequency converters;
   - smaller occupied area and cost as compared to DC-links.

   The above competitive advantages make AEMFC an efficient technical solution for application in energy systems, including ones of metropolitan cities.
2. The electromechanical AC converter was analyzed as to its applicability in energy systems of metropolitan cities such as Moscow for the purpose of:
   - connection of 220 kV grid sections open-circuited as per SCC conditions;

AEMFC CONTROL CHANNELS

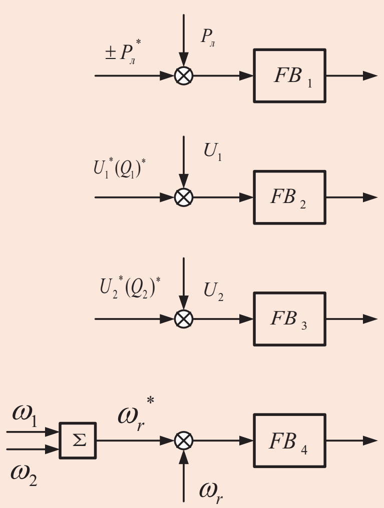


Fig. 9

ACTIVE LPOWER CONTROL

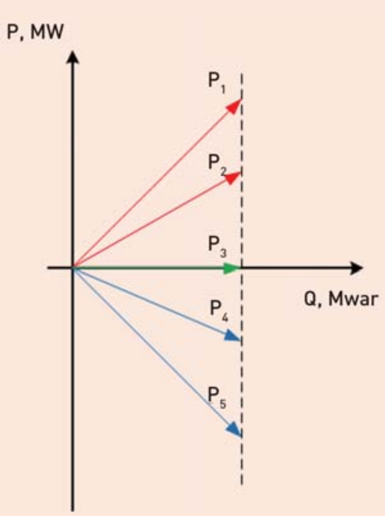


Fig. 10

REACTIVE POWER CONTROL

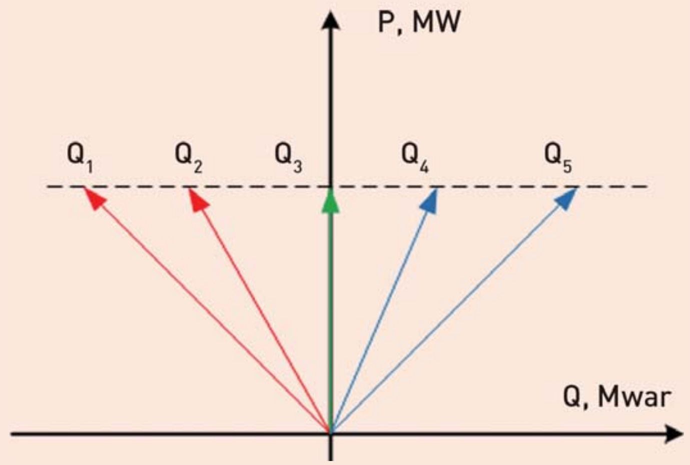
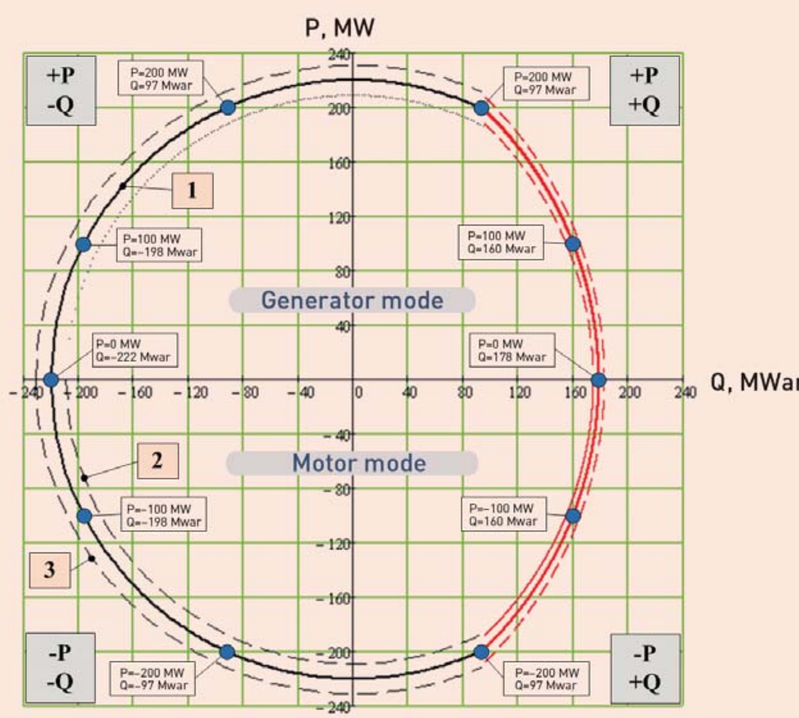


Fig. 11

TOLERABLE MODE RANGES FOR 200 MW AEMFC



1 – with nominal voltage;
2 – with 5% voltage drop;
3 – with 5 % voltage buildup.

Fig. 12

AEMFC PROPOSED INSTALLATION LOCATIONS: SUBSTATION BESKUDNIKOVO 220 KV, SUBSTATION MAGISTRALNAYA 220 KV, SUBSTATION GORKOVSKAYA 220 KV, THERMAL POWER PLANT (TPP) 12, TPP-20, TPP-23

Fig. 13

AEMFC PROPOSED INSTALLATION LOCATIONS: TPP-26

Fig. 14

– controllable active-power flow;
– voltage normalization by adjusting the reactive capacity in wide ranges via generators incorporated in AEMFC, including modes of the advanced reactive power consumption.

3. Possible Moscow facilities suitable for application of electromechanical AC converters are defined. In this case, the following is achievable in 220 kV grids of the Moscow energy system (in the Central Administrative District):

– elimination of separation points in the 220 kV backbone grid at AEMFC installation locations;
– advances SCC reduction in the adjacent 220 kV grid (about 12 kA for one 200 MVA AEMFC, about 30 kA for two AEMFCs, up to 45 kA for four AEMFCs);
– voltage regulation in the adjacent grid by adjusting the reactive capacity in wide ranges via generators incorporated in AEMFC (including modes of the advanced reactive capacity consumption) and, as a consequence, fewer shunt reactors Installed at power facilities within the new 220 kV grid in the Moscow Central Administrative District:
– controllable active-power flow in the 220 kV grid;
– minimization of effects due to 220 kV grid mode restrictions for 500 kV grid operating modes (increase in admissible current flows for 500 kV grids).

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