V. ATABEKOV

ELECTRIC POWER SYSTEM INSTALLATION PRACTICE

MIR PUBLISHERS

ИЗДАТЕЛЬСТВО · МИР ·

В. Б. АТАБЕКОВ

МОНТАЖ ЭЛЕКТРИЧЕСКИХ СЕТЕЙ И СИЛОВОГО ЭЛЕКТРООБОРУДОВАНИЯ

ИЗДАТЕЛЬСТВО «ВЫСШАЯ ШКОЛА» МОСКВА

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Electric Power System Installation Practice

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The Greek Alphabet

Α α	Alpha	Ι ι	Iota	Ρ ρ	Rho
Β β	Beta	Κ ϰ	Kappa	Σ σ	Sigma
Γ γ	Gamma	Λ λ	Lambda	Τ τ	Tau
Δ δ	Delta	Μ μ	Mu	Υ υ	Upsilon
Ε ε	Epsilon	Ν ν	Nu	Φ φ	Phi
Ζ ζ	Zeta	Ξ ξ	Xi	Χ χ	Chi
Η η	Eta	Ο ο	Omicron	Ψ ψ	Psi
Θ θ ϑ	Theta	Π π	Pi	Ω ω	Omega

The Russian Alphabet and Transliteration

А а	a	К к	k	Х х	kh
Б б	b	Л л	l	Ц ц	ts
В в	v	М м	m	Ч ч	ch
Г г	g	Н н	n	Ш ш	sh
Д д	d	О о	o	Щ щ	shch
Е е	e	П п	p	ъ	″
Ё ё	ye, e	Р р	r	Ы ы	y
Ж ж	zh	С с	s	ь	′
З з	z	Т т	t	Э э	e
И и	i	У у	u	Ю ю	yu
Й й	y	Ф ф	f	Я я	ya

На английском языке

Contents

Introduction

The main criterion of technical standards of any country is at present the state of development of its power engineering capacity of power plants, and production of electric energy.

The per-unit power output of turbogenerators and water-wheel generators is ever growing along with the length and rated voltage of high-votage power transmission systems. Power transmission lines rated 800 kV are now in use, and planned for the erection in the near future are 1,000- and 1,500-kV lines.

High-power systems have been organized, in which as many as tens and hundreds of large power plants are interconnected and their operations coordinated with respect to power supply.

A high level of development of power engineering has made it possible to utilize electric energy in leading branches of industry, such as agriculture, construction, and transport.

Electric power sets in motion millions of machines and mechanisms, founds metals, galvanically plates metal surfaces with anticorrosion and antiacid coatings, paints miscellaneous parts in an electric field, automatically controls technological processes and intricate automatic-control lines of machines and conveyers.

The continuous growth of industry is connected with the construction of new factories or the expansion of old ones. A construction or reconstruction of any factory, dwelling house, school, hospital, theatre, etc. is apt to involve a great amount of electrical installation and wiring work.

Installation of electrical equipment on most modern factories includes a great number of complicated jobs, such as:

installation and wiring of factory and shop distribution and transformer substations;

installation of long cable and overhead power transmission lines rated at different voltages;

installation and wiring of shop's metalclad switchgear and control boards;

installation of hoisting and haulage equipment (elevators, hoists, overhead travelling cranes, electric telphers, etc.);

installation of shop's industrial and lighting wiring systems;

installation of ancillary equipment;

installation and wiring of automatic-control, regulation, and monitoring systems.

This intricate work can be done only by electricians who have acquired the necessary theoretical knowledge and practical skill in the job.

This Manual contains all necessary pieces of information on the theory and practice of the installation and wiring of electrical equipment of industrial plants, and also on the organization, industrialization, and planning of the work.

CHAPTER ONE

Electric Power Production, Distribution, and Utilization

1.1. Natural Power Sources and Characteristics of Electric Energy

The material wealth of any society is created nowadays by the common labour of its people. Any work involves the consumption of the respective amount of energy that can be of a different nature, such as muscular energy of human beings or animals, or natural energy.

The muscular energy of human beings and animals was the only source of energy in the bygone days of human society. A continuous growth and expansion of human spheres of activity required more energy that could be taken from natural sources.

The surrounding nature is rich in electric energy resources that differ by their origin and quality, and by methods of their utilization by men. Coal and petroleum deposits, water of rivers and seas, heat of the sun and earth's entrails, force of moving air streams are good resources of energy.

The most efficient utilization of natural resources has become possible with the advent of electricity because almost all the natural energy carriers are actually suitable for the production of electric power.

Electric energy is at present the most popular type of energy and its annual world's production amounts to several thousand billions of kilowatt-hours.

Such popularity of electric energy is attributed to its peculiar features that are not characteristic of any other types of energy known at present.

Electric energy can be:

transmitted over distances as long as hundreds and thousands of kilometres;

easily distributed to many power consumers;

converted to other types of energy, such as thermal or mechanical energy.

Electric energy is most advantageous from the economic point of view. Thermal-electric power plants, for example, use in most cases low-valued types of fuel, such as low-grade coal, peat, shales, etc.

Electric power is generated by power plants or stations which are classified according to the type of energy they use as thermal, nuclear, and hydraulic power plants. Power plants are also classified according to the prime movers as steam-turbine, hydroelectric, gas-turbine, and diesel-electric power plants.

Most large power plants are built nowadays with steam or hydraulic turbines as prime movers.

1.2. Electric Power Plants

1.2.1. Types of Electric Power Plants

An electric power plant is a plant that generates electric power by using energy carriers or by converting various types of energy.

Steam-turbine and hydroelectric power plants are now the chief sources of electric power, although an ever growing number of large nuclear power plants are put into service each year.

Steam-turbine power plants utilize coal, petroleum, natural gas burned in the furnaces of their boilers. The heat generated in the process converts water in the boilers into steam that sets in motion the turbine rotors. The mechanical energy of the turbine rotors is imparted to the rotors of generators wherein it is converted into electric energy.

Nuclear power plants depend for their operation on the same principle as steam-turbine plants, the only difference being that heat is generated in them due to the fission of radioactive elements or their isotopes.

Hydroelectric power plants use water to set in motion the turbine runner. Water power is derived from the force exerted by water in falling through a certain head created by the difference in the upstream and downstream water.

There are also wind-electric, helium-electric, geothermal, tidal, and other power plants utilizing, respectively, the energy of wind, heat of sun rays and earth's bosom, energy of sea and ocean tides.

1.2.2. Steam-Turbine Power Plants

About 80 per cent of electric power consumed in the USSR is generated by steam-turbine power plants. What makes them in favour in this country are their technical and economic advantages, such as:

standardization of buildings and layout of equipment in them;

construction of buildings and their components from factory-made elements;

construction and erection of power plants within the shortest possible time with added advantage of minimum capital investment;

use of power units of high per-unit capacity;

provision for comissioning all the power units of the plant within minimum time.

The main parts of the steam-turbine power plants are as follows:

steam boiler wherein the chemical energy of combusted fuel is converted into the thermal energy of steam that is supplied to the turbine;

steam turbine that functions as a prime mover wherein the thermal energy of steam is transformed into mechanical energy;

electric generator that converts the mechanical energy into electric power.

According to the production process, the steam-turbine power plants are classified as condensing and heat-electric generating plants.

A condensing power plant is used for the production of electric energy only. Feed water for boilers, steam, and condensate circulate in the power plant over a closed circuit.

Figure 1 illustrates a condensing power plant operating on pulverized coal fuel. Lumps of raw coal are supplied by conveyers from a store *1* to a coal crusher *2* wherefrom crushed coal is delivered to the ball pulverizer of a pulverizing compartment *3*. Pulverized coal is drawn out of the pulverizer by a drawing fan and is fed over a pulverized fuel line to a fuel hopper and then to nozzles provided in

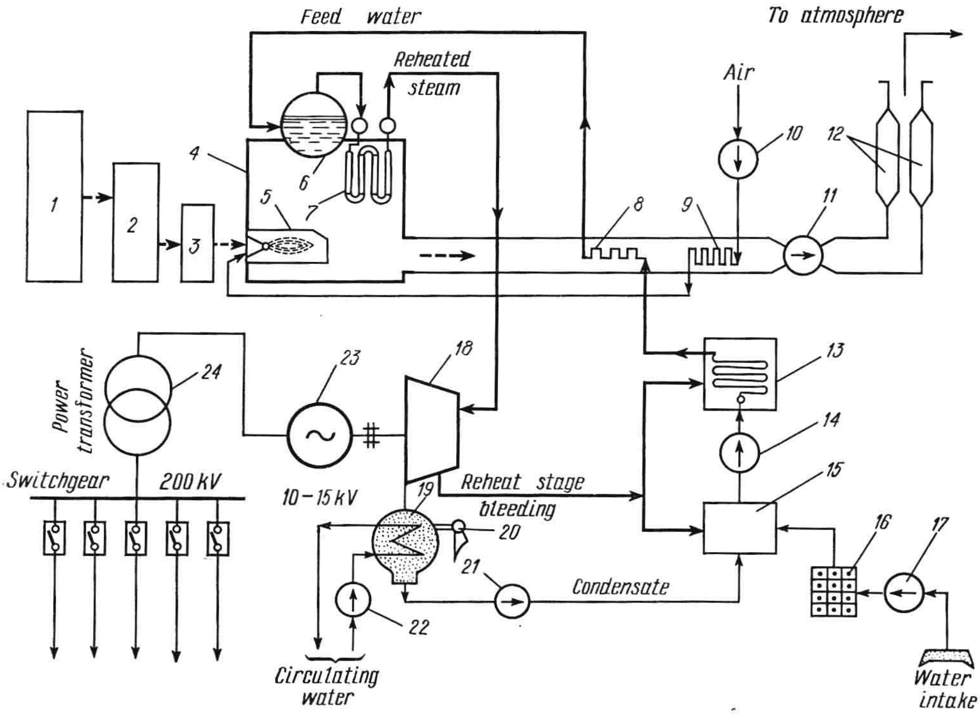

Fig. 1. Schematic diagram of a condensing steam-turbine power plant

1—coal store; *2*—coal crusher; *3*—pulverizing compartment; *4*—boiler; *5*—boiler furnace; *6*—boiler drum; *7*—steam reheater; *8*—economizer; *9*—air heater; *10*—blast air fan; *11*—draft fan; *12*—electric filters; *13*—water heater; *14*, *17*, *21*, *22*—pumps; *15*—deaerator; *16*—water-treatment plant; *18*—steam turbine; *19*—condenser; *20*—ejector; *23*—generator; *24*—transformer

the furnace *5* of the boiler *4*. On its way from the pulverizer to the nozzles, pulverized fuel is passed through a separator wherein large fragments of coal are separated and returned to the pulverizer. Then pulverized fuel is delivered to a cyclone to be separated from air.

Pulverized fuel is admitted to the furnace through nozzles at a definite pressure created by a blast air fan *10*.

The air delivered by the blast air fan *10* to the nozzles and to the furnace (to maintain the combustion process) is heated in an air heater *9* arranged on the path of hot gases exhausted by a draft fan *11*. This is necessary to prevent cooling of the furnace and, in this way, to save heat and to avoid additional consumption of fuel. Hot gases are also used to heat water supplied to the boiler drum *6* in a feed-water economizer (water heater) *8*. Exhaust gases discharged into the atmosphere through a chimney stack are cleaned by electric filters *12*.

Further processes occurring in a condensing steam-turbine plant are described below in a simplified form. Hot gases that are formed as products of combustion of pulverized fuel within the boiler flow over the boiler drum and convert the boiler water into steam which arrives at a steam reheater *7* wherefrom it is passed to the turbine *18*.

Upon leaving the turbine, the dump steam is passed to a condenser *19* wherein it is converted into condensate by coming in contact with tubes of cold circulating water supplied through a pump *17* from a shore pump plant. The pump *21* forces the condensate to the deaerator *15* wherefrom it is passed through a water heater *13* to the economizer *8* and reaches the boiler drum *6* again, thereby completing the closed-circuit cycle.

Feed water supplied to the boiler is also heated in the water heater and deaerator by steam extracted from the reheat stages of the steam turbine. Such an arrangement has made it possible to raise the efficiency of the steam-turbine power plant.

The heat-electric generating plants depend for their operation on the same principle as the condensing plants, the only difference being that the former also supply their neighbouring power consumers (actually, within the radius of up to 20 km) with thermal energy in the form of steam and hot water. For heating, use is made of steam extracted from the reheat stages of the turbine at an appropriate pressure and temperature. This steam is delivered directly to steam consumers or to a heating boiler house for heating the water to be supplied to the hot-water systems.

The prime mover of a steam-turbine plant is a steam turbine. The turbine is coupled to a turbogenerator wherein mechanical energy of the rotating part is converted into electric energy.

The turbogenerator of a steam-turbine plant (Fig. 2) is a horizontal-shaft machine with its shaft *2* coupled to the steam turbine shaft via a half-coupling *1*.

The turbogenerator consists essentially of a stator, a rotor, and an exciter.

The frame of the stator *4* accommodates an iron core that functions as a magnetic circuit. The generator frame is a robust structure made of steel plates lined on the outside with steel sheets. The sheet steel lining consists of two sections, one being welded to the frame and the other, a detachable piece. Cooling ducts passing circulating air are made between the lining and the core.

The core *3* is built up of a number of laminated stacks that are assembled of varnish-coated stampings. The stator stacks are spaced at a certain distance from each other to form cooling ducts for passing cooling air to the generator core and windings. The core is compressed and braced together on both ends with clamping bolts and hold-down strips made of a nonmagnetic material.

The stator slots accommodate a double-layer winding made of rectangular-section insulated copper strips. The winding leads are brought out on both ends of the core and connected into a three-phase winding with concentric end windings.

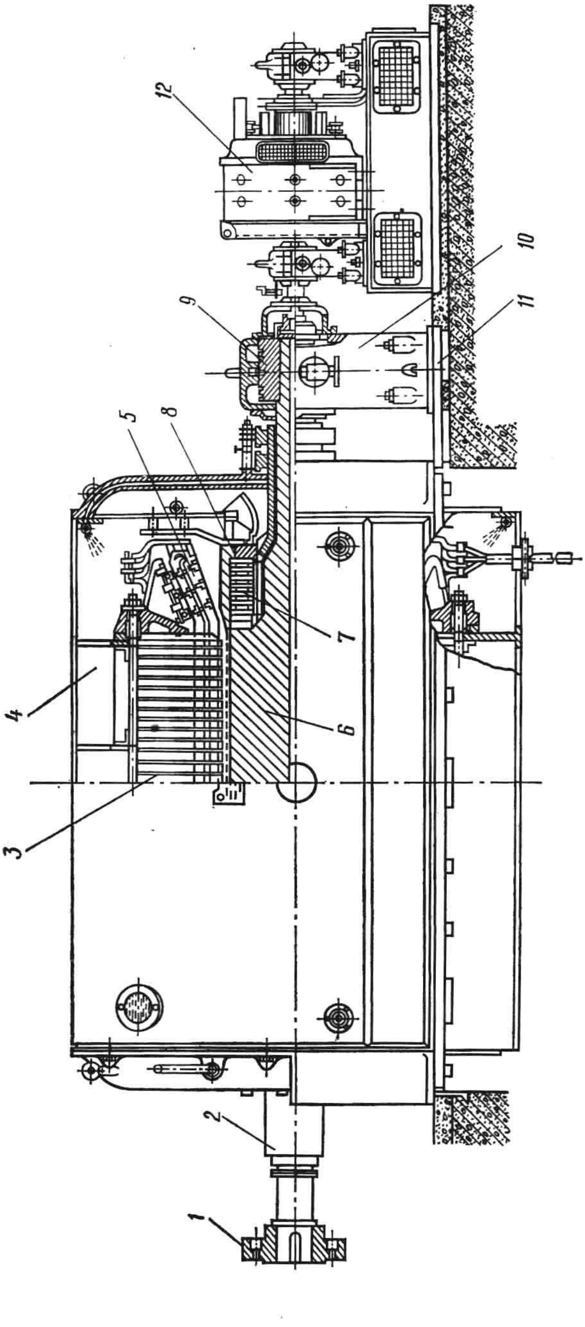

Fig. 2. Turbogenerator

1—half-coupling; *2*—shaft; *3*—core; *4*—stator; *5*—stator end windings; *6*—rotor; *7*—rotor winding; *8*—banding ring; *9*—generator bearing; *10*—bearing pedestal; *11*—bedplate; *12*—exciter

5. The strips are held in position within the core slots by shaped wedges made of an insulating material.

The turbogenerators are furnished with an open-circuit or a closed-circuit ventilation to cool down the core and windings that run hot while the machine is operating. An open-circuit ventilation system is that in which cooling air is admitted into the generator from the outside, passed over cooling ducts, and exhausted outside. In a closed-circuit system, cooling air circulates within the generator in a constant amount and is cooled down by an air cooler.

The iron core and the winding accommodated in its slots are cooled as follows. Heat liberated by the stator copper is dissipated through the strip insulation by air passing through radial cooling ducts of the core and through the air gap between the stator and the rotor. In the action, some portion of heat is transferred from the insulated surface (within the cooling ducts) but the largest amount of hot air is first delivered to the core teeth and only then reaches the air cooler. The core teeth are the hottest spots of the stator core as they take the winding heat and, being smaller in size, they have a rather high flux density and, hence, losses due to nonuniform flux distribution are greater in them.

Hydrogen-cooled turbogenerators are provided with gas coolers placed at the butt ends of the stator.

The cylindrical portions of the turbogenerator stator are covered with detachable end shields with the rotor shaft extensions brought outside through them. Where the shaft extensions leave the generator stator frame, there are oil seals that afford hermetic sealing of the generator frame and prevent hydrogen leakage.

The turbogenerator rotor *6* is a solid forged steel barrel with slots milled in it to receive a winding *7*. The winding is secured within the slots by wedges made of duraluminium or any other nonmagnetic material to prevent closure of the rotor leakage flux through them.

The end portions of the rotor winding are held in position by banding rings *8* that prevent the rotor end windings from being carried away under the action of centrifugal forces set up due to a fast running rotor.

The rotor is mounted in outside bearings *9* that are accommodated in pedestals *10* installed on a bedplate *11*.

The pedestal is insulated from the bedplate by insulating spacers to prevent current circulation over the shaft-bearings-bedplate circuit. Such a bearing current may appear due to the absence or breakdown of a spacer, and also due to a voltage built up across the shaft ends as a result of asymmetric stator field that may be caused by asymmetric magnetic reluctance on the path of the main flux, or by a nonuniform air gap between the stator and the rotor.

Heat liberated by the rotor copper passes through the insulation, then through the rotor barrel, teeth, and slot wedges (and also through the banding rings in the end connections) and is dissipated from the rotor surface by cooling air.

A direct current is required to excite a three-phase synchronous generator by setting up a revolving field as it flows through the rotor winding of the running machine. An exciter *12* functions as a d.c. source. The exciter is mounted on a separate bedplate. The armature shaft of the exciter rotates in its separate bearings and its shaft extension is coupled to the turbogenerator rotor shaft.

Exciting current can also be obtained from mercury-arc or semiconductor rectifiers.

The turbogenerators of modern steam-turbine power plants are noted for a unit capacity as high as 500 and 800 thsnd kW. Under construction are machines of still higher capacity, such as a 1,200-MW generator constructed for the Kostroma steam-turbine power plant.

1.2.3. Nuclear Power Plants

A nuclear power plant greatly resembles the above-described steam-turbine plant as far as processes occurring in it are concerned. The difference is that the boiler unit is replaced by an atomic reactor and a steam generator.

Nuclear power plants use the heat liberated within an atomic reactor as a result of a nuclear chain reaction of some fissionable materials. Fissionable materials used in atomic reactors are called fissionable material fuels. Most useful for the purpose are uranium-235 and plutonium-239.

The heat portion of a nuclear power plant comprises two circuits. The first circuit passes circulating heat carrier and the second circuit conducts heat from the steam plant.

The heat carrier is water circulating at a pressure of 100 kPa and heated within the tubes of the reactor channels up to 540 K. In the second circuit, distilled water contained in the steam generator vaporizer begins to vaporize under the action of the heat carrier and is converted to steam pressurized to 12.5 kPa and delivered first to the superheater and then to the turbine.

A further circulation process is similar to that occurring in a steam-turbine power plant: dump steam extracted from the turbine arrives at the condenser wherein it is converted into condensate which is pumped to the deaerator and then to the steam generator heater and vaporizer.

The working reactor of the nuclear power plant renders the heat carrier, the channel tubes, and the parts and structures within the reactor core and nearby radioactive. All these parts emit radioactive rays that are dangerous to human life.

A double-circuit arrangement makes it possible to avoid induced radioactivity and to keep radioactive steam within the reactor.

Water flowing over the first circuit and passing through the reactor is radioactive. Therefore, all pieces of equipment of the first circuit are accommodated in special cells furnished with anti-radiation facilities.

The reactor is surrounded by a layer of protective water, concrete, and iron to ensure safety and appropriate biological protection, the total thickness of the protective layer being several metres.

Nuclear power plants have found wide application in the USSR. One of the advantages of nuclear plants that makes them so popular is a very small amount of fissionable fuel required for their operation. A power plant of 100 MW capacity, for example, consumes not more than 1 kg of fissionable materials a day.

Planned for the construction in this country in the recent future are large nuclear power plants with fast-neutron reactors. The capacity of some turbogenerators of such power plants will amount to 500, 800, 1,200, and even 1,500 MW.

1.2.4. Hydroelectric Power Plants

Hydroelectric power plants utilize the energy of falling water, the work derived from the water in falling through a given head being equal to the product of the water mass to the water height.

A more complete utilization of water resources on separate sections of a river is afforded by dams and water reservoirs that are constructed to ensure the required head for a cascade of power plants.

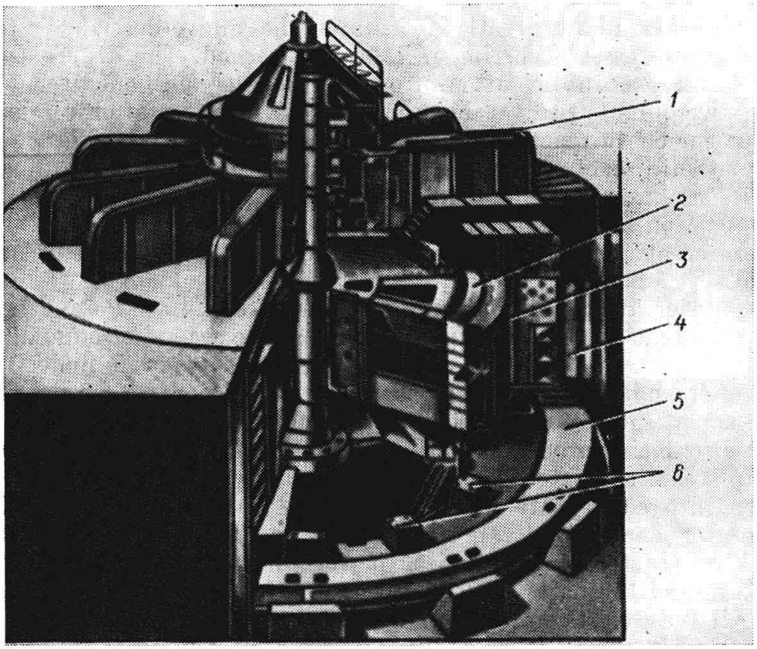

Fig. 3. Water-wheel generator

1—top spider; *2*—rotor and poles; *3*—stator; *4*—air cooler; *5*—bedplate; *6*—lugs

Capacity *P* (kW) of each hydroelectric power plant incorporated in a cascade will be approximately proportional to the water discharge through installed turbines and to the head created, that is,

$$P \approx 9.81 \times QH\eta$$

where Q is water discharge, m^3; H is water head, m; η is turbine efficiency.

The main elements of any hydroelectric power plants are a water-wheel generator and a hydraulic turbine.

The water-wheel generator consists of a stator and a rotor (Fig. 3). The stator and its winding are almost similar in design to those of a turbogenerator, the difference being in the core length and in the number of slots.