Control System of NPP with GT-MHR Power Unit

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0. INTRODUCTION

GT-MHR reactor plant (RP) is a prototype of new modular helium reactors with a direct gas-turbine cycle. The requirements of competitiveness as compared with alternative types of commercial electric power stations are made for GT-MHR RP.

These main requirements are economy, manoeuvrability and safety.

NPP power unit with GT-MHR RP as an object of control is distinguished by a number of features, determining special requirements for control arrangement in operation modes and for structure and composition of monitoring and control systems (MCS).

Thus, the use of one circuit of coolant circulation requires introduction of additional working members to control balance of capacities in the mode the fast change of capacity, the arrangement of a generator, a turbine and compressors at one shaft determines the necessity to introduce additional systems to control power transfer process to keep the required dependences of temperatures on capacity.

MCS of power unit is built as hierarchical distributed system consisting of different subsystems. These separate subsystems are integrated in a unified system on the basis of the all-unit data transmission network, information and calculation system, main control room.

1. BRIEF DESCRIPTION OF GT-MHR RP POWER UNIT AND OPERATION MODES DETERMINING REQUIREMENTS FOR CONTROL. CONTROL PRINCIPLES

The simplified flow diagram of GT-MHR plant is given in Figure 1.

The main GT-MHR RP systems include the following:

- reactor, including the core, graphite reactor, graphite and metallic supports, CPS assemblies, hot gas duct, etc.;

- power conversion unit (PCU), including turbomachine (TM) (turbocompressor and generator), recuperator, precooler and intercooler, supports, gas ducts and seals;

- vessel system, including reactor vessel, PCU vessel, cross vessel;

- frequency transducer, connecting generator with electrical power system (external and house load);

- reactor shutdown cooling system (SCS), independent from the main heat removal system, including gas circuit components (gas blower, heat exchanger and shutoff valve) and water cooling circuit components (pumps, heat exchangers, valves, pressurizer, etc.);

- reacor cavity cooling system (RCCS), providing heat removal under normal operation and possible accidents using passive principles. The system has no controlled equipment, control of technological parameters is provided for it;

- TM control and protection system, including locking and regulating valves, bypass and discharge pipelines, etc.;

- the system of the primary circuit protection against overpressure including protection complexes (bursting-disk device, pulse safety valve and the main safety valve) and pipelines;

- the primary circuit purification system;

- PCU cooling water system (CWS).

2. THE MAIN PRINCIPLES OF PLANT CONTROL

The main task of plant control in the main operation modes with power supply is to set the required reactor power and to keep the required coolant temperature level depending on power.

In GT-MHR plant the reactor power is set and kept by standard way using the system of reactor control and protection by means of the absorbing elements inserted into the core.

As for keeping a required temperature level the main feature of the power unit with GT-MHR RP is the power conversion unit arrangement (PCU), where not only a turbine and a generator but also the compressors, which are stimulus of the primary circuit coolant flowrate, are installed on one unified shaft. The main method to set required temperature level under power operation is to change the coolant flowrate, but as shaft rotation frequency is a constant value it is impossible to keep required temperature level by the change of the rotation frequency of flowrate stimulus.

Taking this fact into account the change of coolant flowrate by the change of its quantity in the circuit is accepted in GT-MHR.

This principle of control requires realizing the system of helium removal from circuit and input into it, the corresponding control system, the working members providing the required manoeuvring rates.

In the transients where the operating speed of the above-mentioned system is insufficient there are such additional means as bypass valves providing bypassing of the part of coolant past the core and turbine, i.e. fast change of conditions of power transfer to the utilities is provided.

The main operation modes of the plant besides the above-mentioned main operation modes, connected with power supply to the electrical power system, are connected with the provision of startup, shutdown, including emergency one, with the provision of the transient on intermediate levels of power with different rates including emergency ones.

The main operation modes of the plant and realization of accepted control principles are described below.

2.1. Dispatcher control mode

The mode is distinguished by the fact that power of reactor and of the entire plant is determined by a dispatcher.

The control principle is standard for NPP, when the schedule of the system power unit loads is available, and the power of this NPP power unit required in prescribed period of time is determined by this schedule. The change of assigned power using CPS is performed by GT-MHR operations staff in scheduled mode with regulated rate.

Simultaneously with reactor power change the follow-up system sets the coolant temperature level required by the static characteristics influencing upon coolant flowrate along the entire circuit by helium content in the circuit. The corresponding control system influences on the working bodies of the helium content control system receiving data on reactor power and on current values of circuit parameters. Specific control laws are determined during design calculation of plant dynamics.

2.2 Load following mode in the power grid

In this case the appropriate control system registers electric current frequency change in the power grid and in accordance with established control laws changes the assigned power level of the plant. CPS influences on absorber element actuators correspondingly.

Helium amount in the circuit control system in accordance with power change influences on its working members establishing circuit parameter values required by static characteristics.

However, among the modes of such type there are such modes for which speed of operation of working members for helium circuit control is insufficient (e.g. at considerable load drop modes in the power grid).

It may lead to inconsistency between turbine power decrease rate and required decrease rate of power unit output that will finally cause unbalance of power generated and consumed by the power grid.

Usually this unbalance is compensated in the grid by peaking power plants of the other type in the event that the grid is sufficiently high-capacity.

In the event that GT-MHR will operate in the local power grid or small power grid the considered situation would lead to turbomachine rotor speed increase (plant variant with synchronous speed of the generator is considered here).

To eliminate turbomachine rotor speedup emergency measures to decrease turbine helium flowrate must be taken in this case.

To this end in GT-MHR plant the bypassing of some circuit equipment by special valves has been accepted. This control principle is used to provide the quickest modes. As helium circuit control system decreases coolant flowrate during the mode, bypass valves are closed.

To coordinate operation of two given regulators it is necessary to determine the most effective relations of the systems to measured parameters, to determine supported parameters, transfer characteristics in control systems. These activities will be realized during R&D based on appropriate calculations of plant dynamics in these modes. Required characteristics of working members will be improved at that.

At the same time it is clear that turbomachine rotor speed must be the main controlled parameter for the bypass valves. The main quality of control is determined by absence of rotor speedup up to emergency speed leading to protection actuation and plant removal from operation.

2.3 Load shedding mode

This mode is characterized by maximal rate and impact depth on the plant from the grid. The grid is fully disconnected; the plant must turn to house loads mode.

The required high control rate requires high initial conveying speed of the bypass valves. In fact turbine helium flowrate must be decreased several times in a split second. High-accuracy control of turbine speed corresponding to the required accuracy of electric current frequency maintenance in house loads power circuit must be provided then. Further when removing helium from the circuit by the appropriate system, closing of bypass valves have to occurre.

The mentioned algorithm of regulators operation requires application of the system of two bypass valves types:

– quick-acting valve providing initial stage of the mode with emergency decrease of turbine helium flowrate;

– valve providing “delicate” helium flowrate control to maintain intended frequency of electric current in the house loads system. Speed of operation of this valve is limited owing to necessity to control helium flowrate with high accuracy.

Helium removal from the circuit and smooth closing of quick-acting valve is carried out after implementation of quick part of the mode and change to electric current frequency control (corresponding low speed of valve displacement in this stage of the mode must be foreseen for that).

At the same time bypass valve to control turbine speed must operate up to the connection of exterior electric power system, whereupon upkeep of generator and turbine speed will not be required.

2.4 Startup mode

The generator operates as an electric motor at the initial stage of this mode. To realize this mode a frequency converter generating electric current of required voltage for generator power supply and frequency during turbomachine startup is used.

Speed of rotation is a controlled value in this mode established in control system by operator or automatically in accordance with regulations.

Generator disconnection from the converter as well as synchronization and grid connection are carried out at obtaining of the assigned speed of rotation and output when the generator stops to consume power from grid.

2.5 Features to organize control at asynchronous speed of the generator

One of the variants of GT-MHR plant realization is the use of increased generator speed which is asynchronous relative to power grid frequency.

In this case between the generator and power grid there is a frequency converter, and generator speed requires to be maintained not only at startup and house loads operation but also in all other modes including main power operation modes.

Taking into account fast time constant of a turbine – generator system as compared to thermal lag of the plant and the system to control helium amount in the circuit, turbine speed must be controlled first of all using control bypass valves as mentioned above.

However, frequency converter may take part in control by means of change of conditions of power supply to the grid. To increase generator speed at a short time a converter carrying capacity may be decreased by means of influence on its thyristors. But such influence must be proven in the reactor and other systems immediately.

Specific control laws and algorithms, transfer characteristics etc. are determined during R&D.

2.6 Electromagnetic bearing control

The use of an active electromagnetic suspension for turbomachine rotor is the feature of GT-MHR. To provide its operation the appropriate EMB control system realized by means of computer aids is used.

Control principles used in this system correspond mainly to the ones presently used in prototype unit of gas-compressor plant type. At the same time, GT-MHR turbomachine rotor characteristics (vertical lay-out, heavy weight at high speed of rotation etc.) require the performance of some investigations based on rotor dynamics calculations as applied to specific turbomachine design and lay-out variants during R&D.

3 STRUCTURE AND COMPOSITION OF THE CONTROL SYSTEM OF NPP POWER UNIT WITH GT-MHR REACTOR PLANT

The control system (CS) of the power unit GT-MHR reactor plant is a complex of interconnected systems realized at the individual program and technical complexes (PTC).

The following characteristics (principles) are used for the determination of individual subsystems (or systems) as parts of CS of the power unit with GT-MHR RP:

technological feature;

subsystem influence upon safety;

functionality;

territorial feature.

The following CS subsystems of the power unit with GT-MHR RP are determined by technological feature:

in-reactor control system (IRCS);

reactor CPS;

CS of PCU equipment;

TM CS;

CS of shutdown cooling system (SCS);

CS of the support system equipment.

To control the actuation of safety and state control equipment in accordance with the requirements of safety specifications, control safety systems (CSS) are provided as a part of CS of the power unit with GT-MHR RP.

Besides CS of the power unit with GT-MHR RP includes subsystem elements which perform the functions of diagnostics and control for all PU equipment independent of its belonging to the definite process system. Such subsystems include the metalworks diagnostic system (MDS) and the radiation safety control system (RSCS).

MDS controls the state of pipelines, vessels and welds of metallic structures of the power unit process equipment. Considerable number of MDS functions is realized in non-operation mode and non-operation personnel of the power unit is the main information user. Based on the information presented by MDS, administrative and technical decisions on the performance of scheduled and unscheduled examinations and repairs of RP equipment are maid.

RSCS realizes a complex of tasks autonomous relative to the other subsystems of PU CS and includes a panel of process systems radiation control.

All-unit data transmission system, PU information system (IS) and main control room (MCR), integrating the aforementioned subsystems of CS into the complex system are considered as the upper level of the power unit with GT-MHR RP CS hierarchical structure.

Figure 2 shows the structure of the power unit with GT-MHR RP CS.

SCS provides the following safety systems state control and actuation in accordance with emergency protection algorithms:

- rod system of the reactor shut down, including 48 rods. All the rods perform the role of emergency protection and may be inserted from any intermediate position.
- the system of localizing valves at the pipelines of primary circuit and cooling water systems of PCU and SCS, including stop valves with pneumatic drive;
- the system of primary circuit protection against overpressure, including two safety complexes in the primary circuit;
- bypass stop and control valves of the control and protection system of turbomachine consisting of four DN 300 valves;
- RCCS as for the state control.

CPS provides reactor control by the displacement of CPS actuators. The control of CPS actuators is provided at the automatic and at the remote control modes operator-aided. CPS provides the realization of the functions of emergency reactor protection and preventive reactor protection including standby reactor shutdown system actuators control. In the course of operation CPS provides control of neutron-physical parameters of the reactor by the signals from the sensors of neutron flux density, which are located both in the reactor vessel and outside the vessel in the reactor cavity.

IRCS is an automated information system intended for continuous operation in the operative circuit of automated RP control.

The main purpose of IRCS is the control of the reactor core state by the data from in-reactor sensors for practical purposes of operation, including the accumulation of analytical information on RP operation and increase of RP operation quality due to it, use of IRCS information for the analysis of emergency situations.

The main purpose of IRCS is the reactor core parameters control, it is provided by the calculation reconstruction of the energy-release and temperature fields in the core by the indication of in-reactor sensors (emission pick-ups and temperature sensors) at the definite control points and by the calculation of the reactor thermal power.

PCU equipment CS provides the control of heat engineering and electric parameters of PCU equipment at all operation states of the system, the control of PCU actuators for all operation modes realization as well as the equipment protection at normal operation disturbance and in the emergency situations including:

-control of process parameters and state of the system process equipment and devices – turbine, high pressure compressor (HPC), low pressure compressor (LPC), generator, heat exchange equipment;

-control of electrotechnical devices of the generator excitement control system;

-control of electromagnetic bearings (is provided by EMB CS).

The main control purposes at the realization of PCU operation modes are:

- control of generator excitement for constant voltage upkeep at the generator buses, voltage vibrations damping at the transitions, increase of static and dynamic stability and limitation of generator overloads at the abnormal operation modes;

-control of electromagnetic TM bearings to provide maximum accuracy of shaft positioning in the central position and realization of the mode of TM fit on the safety bearing (provided by EMB CS);

-control of the valves on the pipelines for cooling water supply to PCU equipment.

EMB CS is an autonomous system from the point of view of control. It is supplied together with TM and serves for EMB control to provide the required load carrying capacity and driving force enough for the stabilization of TM rotor position inside the space limited by catcher bearings at the internal excitement and external effects at all RP operation modes.

In TM design one axial and four radial EMBs are provided.

TM CS provides TM power and frequency conversion control at the modes of RP startup and shut down as well as provides interconnected automatic control of process parameters of the reactor plant at RP operation at the power levels.

TM power is controlled by gas flowrate through the turbine and compressors change by the way of influence upon bypass control valves (bypassing the turbine and core) as well as upon the control valves providing primary circuit makeup and dumping.

The criterion of control quality is the provision, upkeep and change of electric TM power with the required quality as well as PCU parameters upkeep within the operation limits at all modes of normal operation (NO) and non-exceeding of the design limits at the modes of normal operation failure. SCS equipment CS provides the control of SCS gas blower, cooling water system pumps and valves with electric drives.

In SCS gas blower there are electromagnetic bearings, check valve with electric drive of the gas blower and gas blower electric drive including frequency converter and electric motor.

SCS is actuated automatically by EP program. The blockages, pump operation mode change, reserve connection are also performed automatically. The possibility of each unit of equipment remote control from maincontrol room is provided.

CS of the support systems equipment provides the control of purification system equipment, helium transportation and control, auxiliary systems equipment, performing heat removal from RP equipment at power operation and at cooling down as well as primary circuit coolant parameters control (before and after purification).

Power unit control is performed from the room of the main control room (MCR). MCR is intended for the centralized control of the whole power unit at normal and emergency conditions.

In the room of MCR there are working places for PU operator (RP operator), PU shiftman, specialist in radiation control, CS engineer, specialist in diagnostics. Everybody has his own working place.

The main means of information presentation on MCR are coloured graphic monitors, symbolic circuit and some individual devices.

Manipulators (of “mouse” type or “track-ball” type), alphabetical-digital and functional keyboards are used as control members.

Working place of PU operator differs from the other working places. There together with the aforementioned information presentation means and control members, the location of individual indicating devices and traditional keys and buttons is provided. Given control means belong first of all to the control safety means and are located on special emergency panel in the operative zone.

Some functional (hierarchic) levels form the structure of main subsystems of the power unit with GT-MHR RP CS.

Component level is formed by primary converters, normalizing transformers and power execution automatic machines as well as automatic equipment, which commutates force voltage to the actuators electric drives.

The next level, which is called ***system level*** consists of local systems and control means.

The presented system levels provide the realization of automatic control functions and logics of remote control, thereby the performance of the mentioned functions in the volume necessary for the provision of safe operation conditions is provided without the participation of upper CS levels of the power unit with GT-MHR RP.

The third ***(“common”) level*** of CS of the power unit with GT-MHR RP consists of the all-unit means and systems performing efficient integrated processing of technological information about PU and providing interaction with operations stuff and its information support. Common level means provide the integration of individual CS subsystems of the power unit with GT-MHR RP into the united system.

To provide the reliability of control functions realization in CS of the power unit with GT-MHR structural reservation is used. The reservation is provided at the level of sensors and devices of the systems. When determining the degree of reservation the importance of the realized function for the purposes of safety and reliability of main RP operation modes provision is taken for the basis.

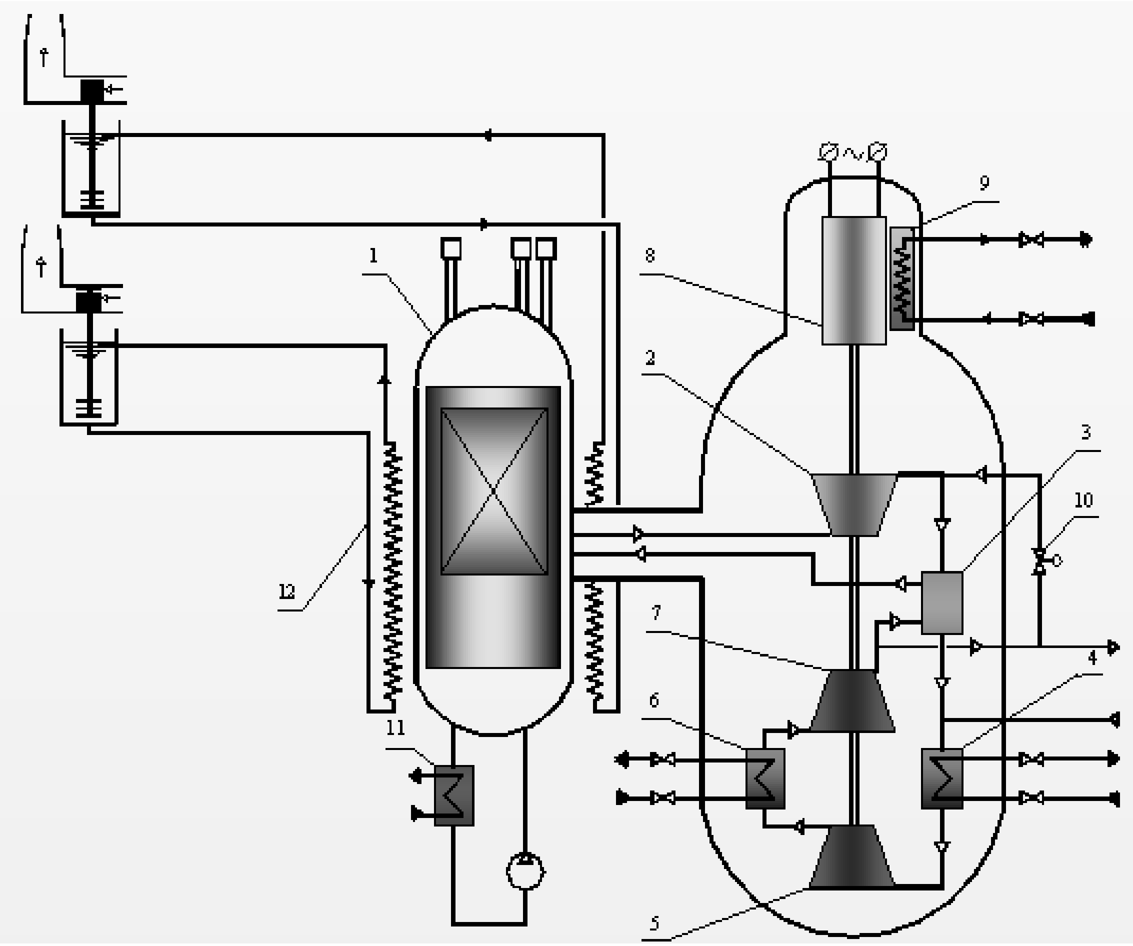

Fig.1 – Simplified diagram of GT-MHR RP: 1–reactor; 2–turbine; 3–recuperator 4 - precooler,
5 - compressor; 6 - intercooler; 7 – compressor; 8 – generator; 9 – generator cooler; 10 – control
and safety turbomachine valve; 11 –SCS auxiliary heat exchanger; 12 – RCCS heat exchanger.

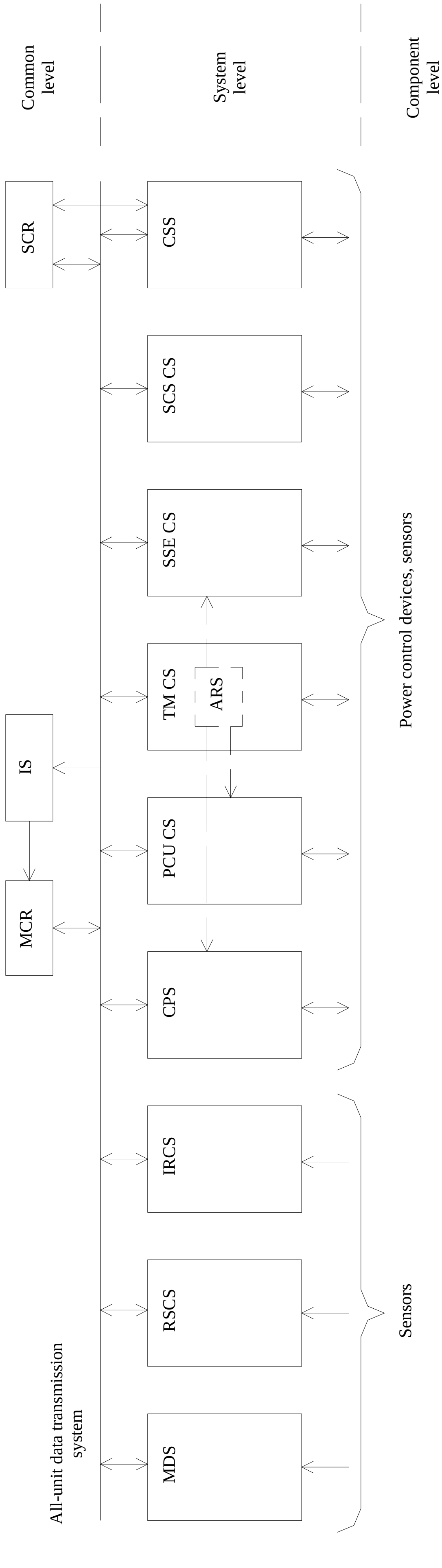

Fig. 2 - CS diagram of NPP with GT-MHR power unit