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CLASSIFICATION OF POWER RESERVES OF ELECTRIC POWER SYSTEMS

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INTRODUCTION

Single Electric Energy System of Russia (SEES) is one of the largest energy systems in the world. It includes 69 regional power systems that, in turn, form seven interconnected power systems (IPS), namely: IPS of the East, IPS of Siberia, IPS of the Urals, IPS of the Middle Volga, IPS of the South, IPS of the Centre, and IPS of the North-West. Electric energy complex of SEES of Russia includes more that 700 power plants whose capacity exceeds 5 MW. As of the end of 2013 the installed capacity of power plants within SEES of Russia totalled 226,470.18 MW. All the IPS are connected by inter-system high-voltage 220-500 kV (and higher) power lines that operate in parallel [1]. Power system of the Crimea is currently referred to technologically independent power systems (PS) of Russia.

The main specified functions of IPS are [2]:

- Functions related to their purpose;
- Functions related to the fact of their creation.

Ability of the object to perform the specified function stipulated by its purpose is referred to as power supply reliability [3-5]. The purpose of a power system is to supply power for consumers. Power supply reliability is PS ability to supply consumers with the power of required quality and following the specified power consumption schedule. Power supply reliability is ensured by: change in the power system configuration and structure, including control means; change in the reliability and in other performances of its components (the main and auxiliary equipment, control devices); creation of different redundancies (power reserve, transmission capacity reserve for power lines, fuel stock at thermal power plants (TPP), water stock at hydro power plants (HPP), etc.; perfection of PS operation [6].

CAPACITY RESERVE

Capacity reserve is one of the main ways of raising the power system reliability. Reserve (réserve in French) is a stock of something for the case of need; a source of new materials, forces [7]. Capacity reserve is a method of raising the object reliability by incorporating the redundancy. As applied to power systems we consider structural, functional, temporal and informational reserves [6].

Capacity reserve may be located in the generating and consuming parts of the system [8] (Fig. 1). Difference between the available PS capacity and its load at a given time moment is referred to as generating capacity reserve of the system [6]. *Reserve in the consuming part of the system is power the consumer is ready to forsake on the reimbursement base in case of the PS operation failure.* Maintaining the balance between power production and consumption that is ensured at the expense of consumers should be considered as a temporary measure and, as a rule, is used in the emergency and post-emergency PS operation provided that all the generating capacity

reserves of required mobility have been exhausted. If necessary, the generating capacity reserve of required mobility will be recovered by the reserve start-up in the consuming part of the system. At the same time the availability of generating capacity reserves (but of insufficiently high mobility) and its further start-up would allow connection of disconnected consumers, i.e., reserve recovery in the consuming part of the system. Thus, in this event the generating capacity reserve is replaced by the reserve of the consuming part of the system and vice versa.

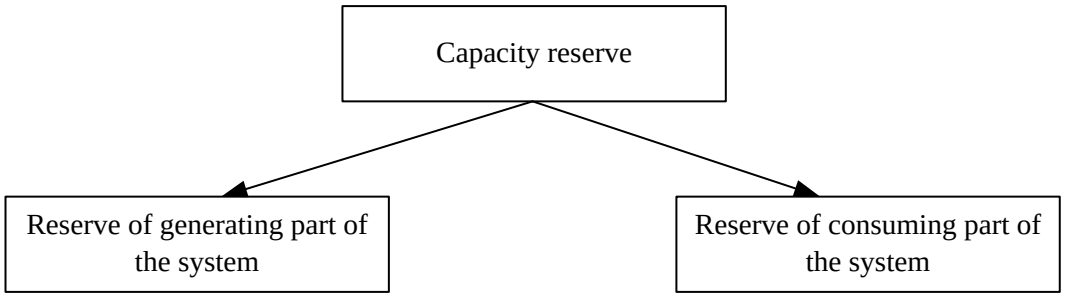

Fig. 1 Power reserve location in the system

GENERATING CAPACITY RESERVE

Functionally the PS generating capacity reserve is divided into two components: maintenance reserve and operating reserve.

Maintenance reserve is needed for balancing the reduction of PS working capacity when the main equipment of the system is under scheduled maintenance or modification [6]. Scheduled maintenances are deemed to be the main way of controlling the technical state of equipment and restoring its resource. Scheduled maintenances include regular maintenances of equipment and equipment overhauls.

Operating reserve is intended to balance the imbalance between power generation and consumption that is caused by equipment failure and sudden deviation of consumer load from the expected value. For this reason the operating reserve is divided into emergency reserve and load reserve (Fig. 2). Emergency reserve is needed for compensating the losses of power used for meeting the load at emergency and during non-scheduled shutdowns of the main equipment of power plants. Load reserve is intended to balance the power imbalance caused by load deviation (its growth or fall) from the expected one. Unfortunately, currently there is no sufficiently well grounded classification of the operating reserve of generating capacity except for its division into emergency and load reserves.

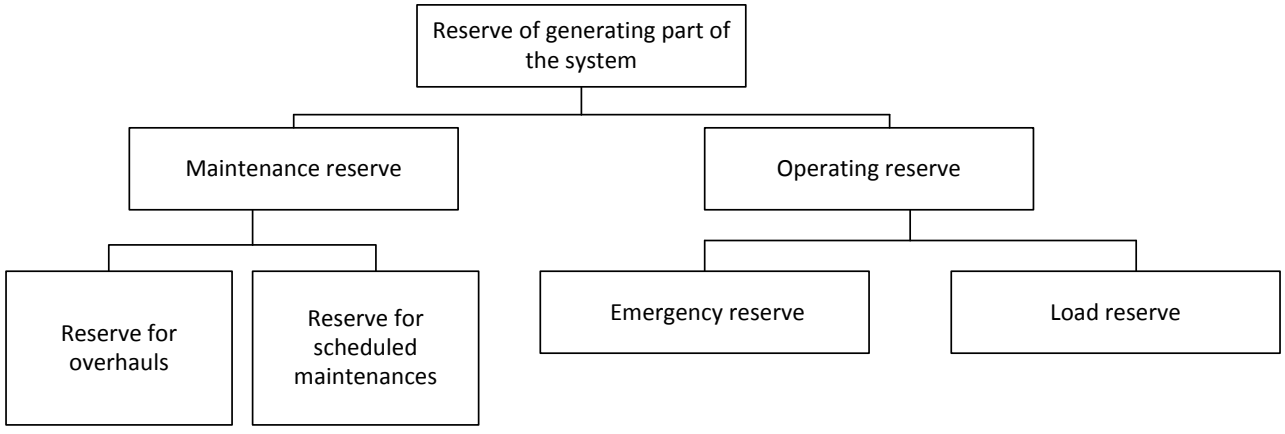

Fig. 2 Classification of generating capacity reserve

Terminology used in literature for engineering workers can mislead the reader. Some examples:

- «Operating ("hot") capacity reserve is a share of a capacity reserve intended for balancing the imbalance between production and consumption that is caused by equipment failures, emergency or accidental reduction in the PS operating capacity or by unexpected on-line increase of the consumer's load" [1]. According to this definition hot reserve is actually an operating reserve.
- "Hot (or spinning) reserve is created by boilers under steam pressure and by idle running turbine generators" [9]. According to this definition a hot reserve is a spinning reserve.
- "Spinning reserve of active capacity is capacity reserve located at operating units and units with the start-up time of up to 5 minutes" [1]. According to this definition the fast-start reserve is also a spinning reserve.
- "Cold reserve is ensured by special reserve units with small start-up and spin-up time" [9]. Period of the cold reserve start-up is deemed to be from 2 to 24 hours and more. Units with small start-up time usually have a power-on reserve.
- A hot reserve is sometimes referred to a power-on reserve though time of its start-up makes 1-2 hours, whereas start-up time of the power-on reserve is just minutes [6, 10]. A hot reserve should be referred to a standing reserve.

Further we give classification of the operating reserve that takes into account such characteristics as state of equipment on which the reserve is located, method of its start-up, mobility degree and functionality.

An operating reserve of generating capacity is located on the equipment that can be in different states. Depending on the equipment state it can be the power-on and standing reserve (Fig. 3).

Under the power-on reserve we mean reserve capacity of currently operating units that can be used immediately (started-up in minutes). A power-on reserve includes:

- A spinning reserve is an operating reserve of the system that is placed on the operating underloaded units of power plants;
- A fast start-up reserve is an operating reserve of the system that is placed on the fast start-up units whose full loading time does not exceed the time of spinning reserve start-up.
- A standing reserve is capacity of idle properly operating units of power plants within the energy system. A standing reserve equals to difference between operating and power-on capacity of the power system. Standing reserve includes:
- A hot reserve of the system is an operating reserve located at TPP units where a boiler is in hot reserve [10].
- A cold reserve of the system is an operating reserve located at TPP units where boilers are in cold reserve.

It should be mentioned that a hot reserve of the system also includes an operating reserve located at TPP with transverse relations where the boiler is maintained in the hot state, and the turbine generator is shutdown.

When the boiler is immobilized for a hot reserve, the specified steam pressure and temperature are maintained in it.

A power-on reserve is started-up into minutes, whereas activation of a standing reserve requires 1-2 hours and more.

Functionally (with account of mobility) we can single out the following types of reserves:

- First priority reserve for primary frequency control (started up into seconds);
- Second priority reserve for secondary control (power flows limitation; started-up into tens of seconds);
- Third priority reserve for the secondary control (frequency control and control of power flows over transmission lines; started-up into up to five (5) minutes);
- Fourth priority reserve for tertiary control (fast mode adjustment for the system transition into a more preferable (from the standpoint of reliability) state, including for restoring the control range of power plants connected to an automatic load-frequency control system; start-up time is up to 15-20 minutes;
- Fifth priority reserve for balancing the power imbalances and for complete optimization within the considered hour of the system operation;
- Sixth priority reserve for compensating the power imbalances that can be identified at a lead time exceeding the start-up time of a standing reserve (replacement of the fifth priority reserve and optimization of operating conditions within the considered day of the system operation).

Thus, we can conclude that *a power-on reserve is a reserve that ensures primary, secondary and tertiary control in PS.*

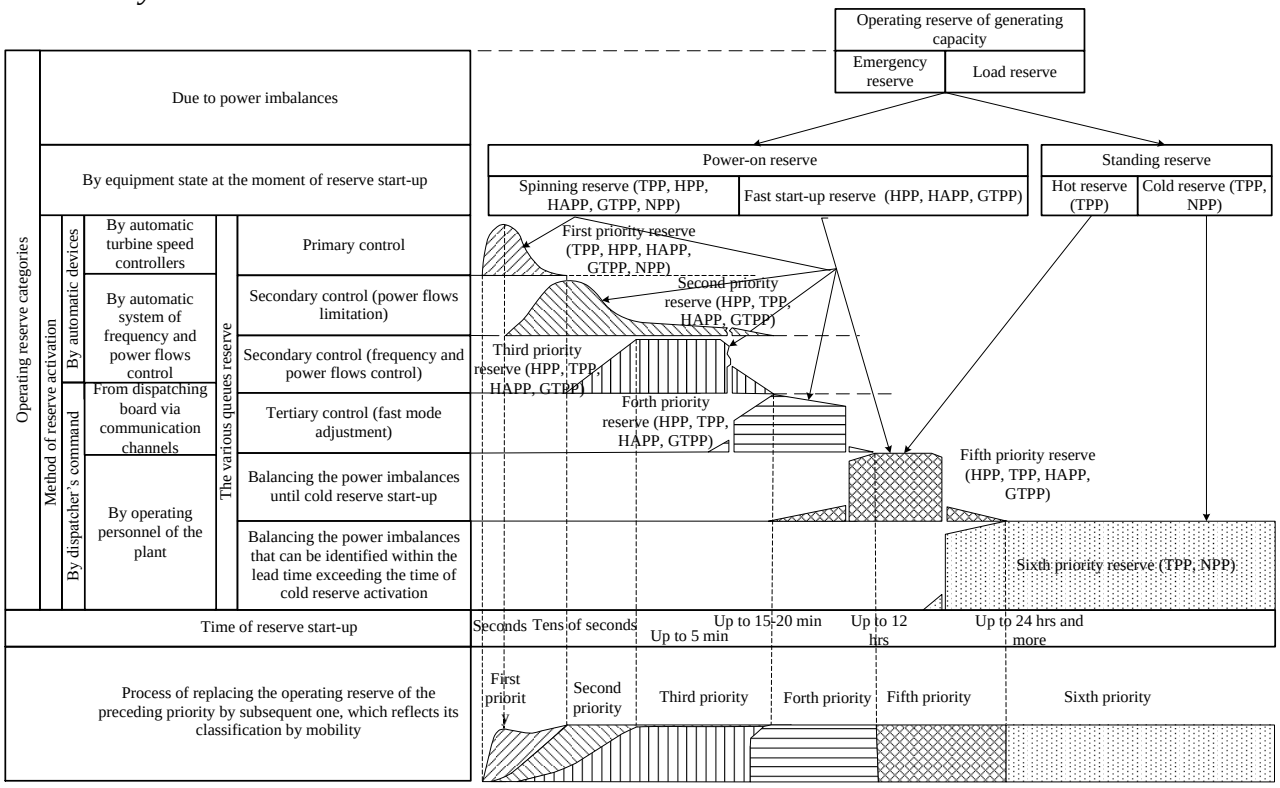

Fig. 3. Classification of the operating reserve of generating capacity of the system

(Note: HAPP – hydroaccumulating power plants; GTPP – gas-turbine power plants; NPP – nuclear power plants)

Within the first several minutes the power imbalance is covered by the first priority reserve that is started up by turbine speed control within several seconds (primary control). Primary control is characterized by certain statics and does not maintain the required frequency.

Secondary control ensures recovery of the given value of frequency and power flows in the cross-sections where they are controlled. In this case units of power plants that are not involved in the secondary control but participate in the primary control go back to initial operating mode.

For restoring the control ranges of power plants connected to an automatic load-frequency control system the reserve is started up by the operating personnel of power plants following dispatcher's command or directly from the dispatching board of the system (fast adjustment of operating conditions), i.e., tertiary control.

Subsequent (slow) economic adjustment of operating conditions is done observing all the limitations related to the fifth priority reserve start-up. A reserve ensuring the tertiary control in this case becomes available. Sixth priority reserve is started up and releases the fifth priority reserve for reducing the operating costs in the system. Such an alternate start-up and replacement of reserve of the preceding priority by the subsequent one ensures the required controllability of the system.

RESERVE OF THE CONSUMING PART OF THE SYSTEM

Similarly to a generating capacity reserve a reserve of the consuming part of the system participates in the power and frequency control. Functionally the reserve of the consuming part of the system is an operating and maintenance reserve (Fig. 4).

Operating reserve is deemed to be the capacity spared due to disconnection or limitation of consumers for balancing the power imbalances caused by emergency shutdown of generating and main equipment or in the event of load excess over the expected one.

Maintenance reserve is deemed to be the capacity spared due to disconnection or limitation of consumers for balancing the power imbalances caused by scheduled maintenances of generating equipment in the event of insufficient maintenance reserve of generating capacities in the power system. In the event of insufficient or lack of generating capacity reserve the reserve is formed at the expense of consumers since operation of electric power systems (including maintenances of generating equipment) without generating capacity reserve is not possible. Thus, generating capacity reserve in these events is formed owing to efficient use of reserves in the consuming part of the system. The difference between a generating capacity reserve and a reserve in the consuming part of the system lies in the fact that *the generating capacity reserve is, as a rule, a structural reserve, whereas reserve in the consuming part of the system can be considered as an example of a functional reserve.*

Further we consider classification of the operating reserve in the consuming part of the system.

Depending on the cause of power imbalances this reserve is divided into emergency and load ones (Fig. 4).

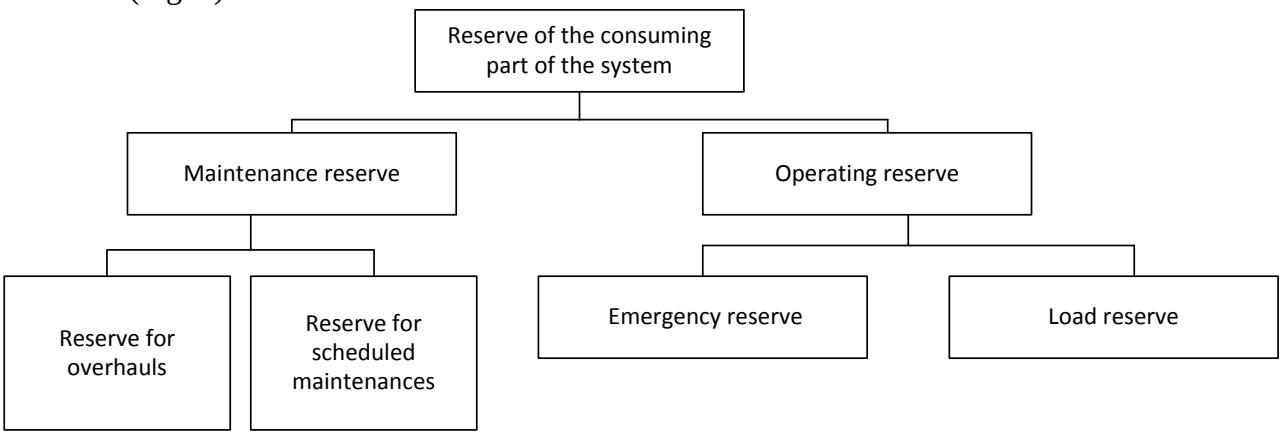

Fig. 4 Classification of the reserve of the consuming part of the system

Load reserve is deemed to be the capacity spared due to disconnection or limitation of consumers for balancing the power imbalances caused by deviation of the load from expected one. An emergency reserve in the consuming part of the system is capacity spared due to disconnection or limitation of consumers for balancing the power imbalances caused by emergency shutdown of the generating and main equipment of the system.

Reserve of the consuming part of the system includes consumers with controllable load and consumers-controllers.

A group of consumers with controllable load includes consumers that due to their operating conditions can rapidly reduce power consumption from the network. Such consumers provide (on the reimbursement base) services for emergency avoidance in the Single Electric Energy System of Russia. Certain groups of consumers are offered special (lower) tariff on condition that they can be disconnected at any moment should such an event occur in the network [1].

A load consumer-controller is a power or heat consumer whose operating mode allows power or heat consumption limitation both in emergencies and in peak hours for levelling the load schedule in the power system and for raising the load during periods of minimum consumption. Based on the difference between the basic and privileged tariffs one can assess the economic efficiency of HPP share in the manoeuvrable secondary frequency control after emergencies or after considerable imbalance between power production and consumption in PS [11].

Classification of the reserve of the consuming part of the system based on its functionality with account of mobility is given in Fig. 5.

With account of the consumers' state at the moment of the reserve start-up the operating reserve is divided into power-on and standing reserves:

- A power-on reserve: its start-up time exceeds several minutes (not more than 10-15 minutes);
- A standing reserve: its start-up time does not exceed 12 hours.

A power-on reserve includes:

- Consumers ensuring the load control effect;
- Consumers with controllable load that are connected to the Automatic Load Disconnection System (ALDS) and to the Automatic Line Overload Limitation System (ALOLS);
- Consumers connected to the system of automatic underfrequency load shedding systems I&II;
- Consumers that can be disconnected following the dispatcher's command or directly from the control board.

A standing reserve may include consumers that allow limitations.

A consuming part of the system participates in primary, secondary and tertiary frequency and power control and in balancing the power imbalances by starting up the standing reserve (by limitation of consumers).

Primary control is performed, first, due to load control effect (in the event of frequency raise the primary controlling power of interconnected consumers is positive, i.e., consumption grows; in the event of frequency fall it is negative, i.e., self-unloading occurs), second, by emergency control

devices (underfrequency load shedding systems I, ALDS, and ALOLS). Start-up time is from fractions of seconds to 0.3 second [12].

Secondary control is performed by consumers connected to underfrequency load shedding systems II. Time of the reserve start-up is up to 90 seconds.

Tertiary control is ensured by consumers disconnected by a dispatcher, and by consumers-controllers (ensuring fast adjustment of the operating mode) that are ready to reduce (raise) the power consumption following the dispatcher's command. Time of the reserve start-up is up to 15 minutes.

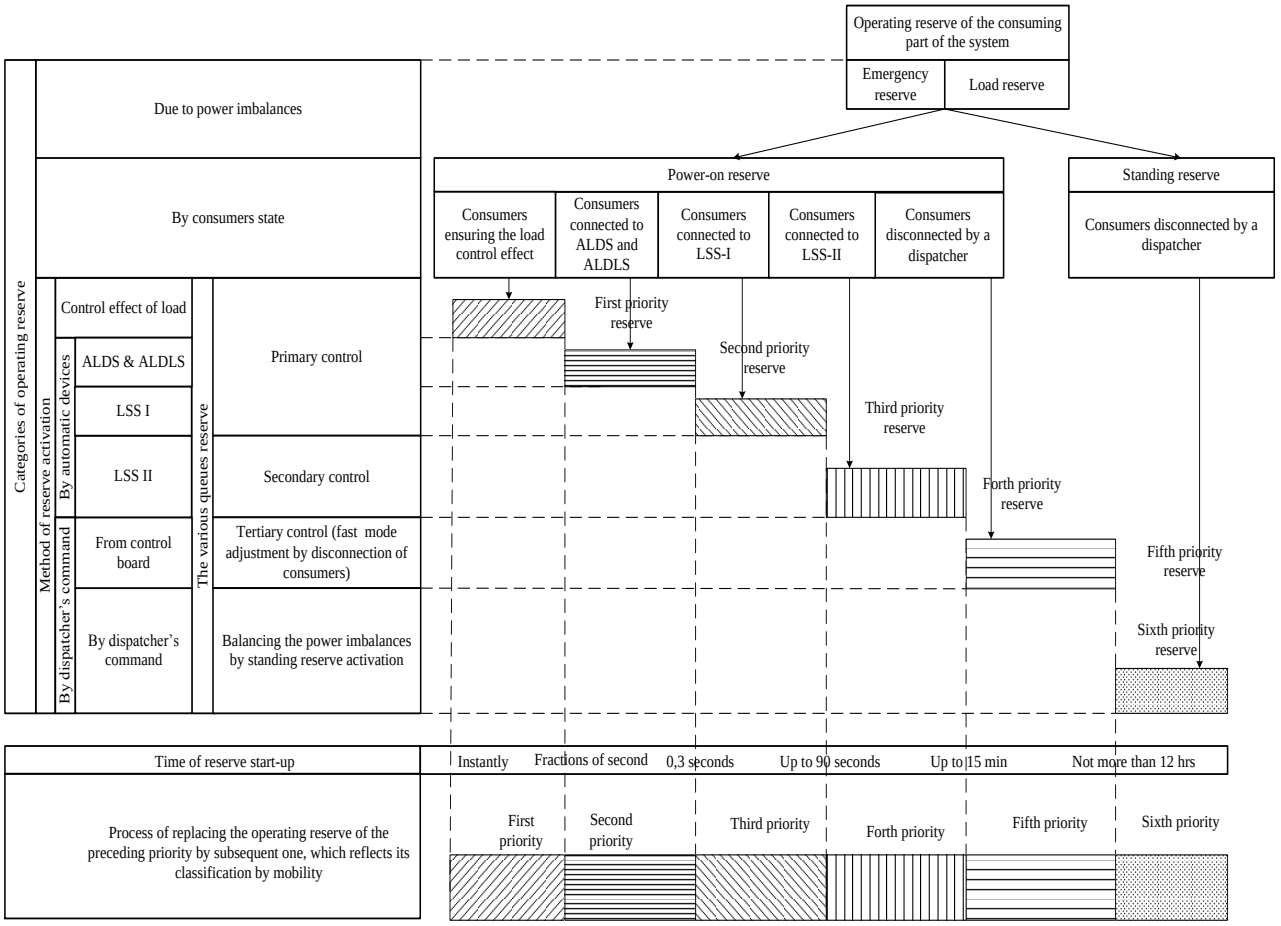

Fig. 5. Classification of the operating reserve in the consuming part of the system.

Now we may offer classification of the operating reserve of the consuming part of the system based on its functionality with account of mobility:

- First priority reserve for primary frequency control due to load control effect (started up practically instantly);
- Second priority reserve for primary frequency control and power flows limitation owing to using the reserve located at consumers with controllable load that are connected to ALDS and ALOLS systems (started-up into fractions of seconds but it is less than start-up time of the reserve connected to the underfrequency load shedding system I (LSS-I));

- Third priority reserve for primary frequency control due to using the reserve located at consumers connected to the underfrequency load shedding system I (started-up in not more that 0.3 seconds);
- Fourth priority reserve for secondary frequency control due to using the reserve located at consumers connected to the underfrequency load shedding system II (LSS-II); start-up time is not more than 90 seconds;
- Fifth priority reserve for tertiary control due to using the reserve located at consumers that are disconnected by a dispatcher from the control board; start-up time is not more than 15 minutes;
- Sixth priority reserve for balancing the power imbalances by starting up the standing reserve located at consumers that allow temporary power limitation; start-up time is not more than 12 hours.

Consumers are disconnected and limited in accordance with the schedules of emergency disconnection or limitation of consumers.

Schedules of limiting the electric capacity use mode and schedules of limiting the electric power consumption mode are schedules according to which the consumers are preliminarily notified about the need to limit the electric power (capacity) consumption and they themselves perform technical (technological) measures ensuring the consumption reduction in the volumes and in the periods of the day indicated in the notice. Such schedules can be implemented without disconnection of the energy receiving devices and/or power lines.

Grounds for using the schedules of emergency limitation of power (capacity) consumers include occurrence or threat of occurrence of emergency conditions, when parameters of electric conditions go beyond the permissible values, including due to [7]:

- Occurrence of non-permissible power shortage and capacity in the power system or in its separate parts that leads to the electric current frequency shedding below 49.8 Hz or to voltage reduction below minimum permissible levels;
- Insufficient power and electricity production in separate parts of the system that leads to inadmissible overload of power lines, transformers and other main equipment or originates the risk of such overload;
- Damage of the main equipment, including in the event of emergencies, natural and man-induced disasters;
- Damage of technological control systems, technological networks and emergency control devices.

Schedules of temporary disconnection of consumers are schedules following to which the power producing company disconnects power lines without preliminary notice to consumers. Disconnection of power units directly by consumer's staff is also possible.

Schedules of temporary disconnection of consumers are activated if it is impossible to apply the schedules of power consumption limitation mode in the time period needed for preventing the emergency electric conditions, in the event the consumers do not follow dispatcher's commands on activating the power consumption limitation mode, as well as in the event the causes necessitated the activation of power consumption limitation mode persist after introduction of the consumption limitation mode.

Power Supply Company shall notify the consumers about temporary power disconnection schedules immediately after their activation.

Schedules of power (electricity) consumption limitation mode are introduced starting from 0 hr 00 min of the following day. The power supply company shall notify the power consumers about that not later that at 2:00 pm of the current day [13].

Schedules of power (electricity) consumption limitation mode are introduced following the dispatcher's Order of the regional dispatching board. The Order shall include:

- Area (operating zone, power sector, and/or power facility) where emergency limitations are introduced;
- Grounds for limitations;
- Time of the limitations start and end.

Primary receivers of commands on emergency limitations distribute the limitation volumes specified by a dispatching centre and deliver information on introduction of the consumption limitation mode to secondary receivers of commands on emergency limitations and to appropriate power supply companies.

In the event some consumer does not follow the commands on introduction of power consumption limitation mode, the operating personnel of the main company has the right to disconnect that consumer from power supply centres, up to the emergency reservation [13].

SUMMARY

1. Definition of the operating reserve of generating capacity is given vs the state of equipment it is placed on. Based on that feature the spinning reserve, fast start-up reserve, hot reserve, and cold reserve are distinguished.
2. Consideration is given to such notions as power-on and standing reserves, their relation to the spinning reserve, fast start-up reserve, hot reserve, and cold reserve.
3. It has been shown that primary, secondary and tertiary control in the power system is ensured by the power-on reserve of generating capacity.
4. The given classification of the operating reserve of generating capacity is based on its functionality with account of mobility. Several priorities of the reserve have been singled out, which allows one to: make correlation between the method of the reserve start-up and its mobility; uniquely determine requirements to the operating reserve the observation of which would ensure the required controllability of PS owing to automatic devices and operating &dispatching personnel.
5. Definition of the reserve in consuming part of the system has been proposed (first).
6. Classification of the reserve in consuming part of the system has been given with account of its mobility and functionality.
7. Consideration was given to capabilities of the reserve of consuming part of the system under primary, secondary and tertiary control.

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