Stability and reliability of power system operation due to use of renewable energy resources

Viktor Elistratov, Irina Kudryasheva
Civil Engineering Institute
Peter the Great St. Petersburg Polytechnic University
St. Petersburg, Russia
elistratov@spbstu.ru, kudryasheva_ig@spbstu.ru

***Abstract*—The program of measures to introduce modern resource-saving technologies for the most effective management of renewable resources will provide the necessary amount of energy to both the population and industrial enterprises. The energy power supply system includes energy power plants using various renewable energy sources (hydraulic, wind, solar) that create more favorable conditions for its stability modes. Unification of power plant using various renewable energy sources (hydraulic, wind, solar) in power supply system has created more favorable conditions for use of power resources. These power plants have their own features of operation modes and definite work place in the production schedule of power supply system. During power supply operation daily production schedules define an operating mode of the system as a whole, including all its elements, from generating sources to high-voltage transmission lines and distributive networks system. The results of given researches are allowed to create the methods of increasing stability, reliability and efficiency supply systems with using renewable energy sources.**

Keywords—power plant, renewable resources, operation modes, power supply system, hydropower plant operation modes, daily power production schedule, pump storage power plant, wind power plant, photovoltaic plants, energy complex.

I. INTRODUCTION

The program of measures for the further development of renewable energy sources has provided in Russia [1]. The creation on this basis of new environmentally ft generating capacities will allow for the technical and technological re-equipment of existing hydroelectric power plants, based on the use of modern technologies [2]. Effective water resources management, taking into account international best practices, will improve the balance of energy resources and meet the needs of enterprises and the population in electric energy. Creation of new and modernization of existing generating facilities should be based on the introduction of modern and sound technical solutions, effective resource management, preservation of the existing flora and fauna. Modern management methods of hydro power plants, pump storage power plants, wind power plants, photovoltaic plants and characteristics of wind and solar energy arrival forecast, redistribution and accumulation by modern technical means can provide steady and reliable of power supply operation in Russia and other countries [3-6].

II. HYPOTHESIS

The most important problem that has to be solved during the operation of the power system is the most efficient redistribution of the produced energy, i.e. coordination of the schedule for the production and consumption of electricity at different time intervals. The consumption process or load schedule is uneven depending on the rhythm of a person's life, the nature of consumption, etc. One of the most important ways to improve the reliability and controllability of the power system is the effective redistribution and accumulation of generated energy.

Therefore, a change in electricity generation can not be accomplished without a corresponding change in the demand for it from consumers, the readiness of high-voltage power lines and distribution networks to bring electricity to consumers.

In the world practice of large energy system operating the solution to the problem of uneven electricity consumption is achieved different ways. First of all it is creating of special maneuverable power equipment (peak power plants, gas turbine power plants), and secondly by using accumulate systems (AS) that consume surplus electricity during periods of general decrease in the load in the power system and supply it during periods of increased consumption [1-9].

III. METHODS

The random processes theory, methods of mathematical statistics and situation modelling using at this report have allowed to account for the influence of random factors. Thus, the production schedule can be predicted with certain degree of probability. The methods of mathematical statistics on the basis experience of west researches for the objects RES-based power plants give possibilities to obtain their own working characteristics and place of work in the load schedule of the power system. Situation modelling allows to account the features and modes of plants on the renewable energy sources.

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IV. Results and Discussions

A. Hydropower plant operation modes

Hydropower plant (HPP) units are highly maneuverable due to their technical features and can be quickly switched on and off: it takes up to 1-2 minutes to start up from the stopped condition. As the HPP can be completely disconnected at night and worked by the installed capacity in the peak production hours its adjustments range equals to the unit.

The hydropower plant mode operating in a power supply system depends on the water flow, reservoir volume, kind of flow regulation, requirements of power supply system, ecological requirements, requirements of other water users and water consumers. The hydropower plant can be used in a power system for power generation, covering of load peaks, rendering of system services, including regulation of frequency, loading and emergency reserve, for development of jet power as the synchronous jack [1, 2].

According to reservoir volume the hydropower station can carry out a daily (Fig. 1) and week operating mode in the power system. Daily regulation provides night decrease power of HPP and increase power in the schedule peak. The daily operating mode can be limited and unlimited. The mode can be limited in case of: 1) small reservoir volume; 2) requirements of flows and levels maintenance in bottom; 3) ecological requirements of sanitary outflow for water consumers and water users. In Fig. 1 it is shown the limited daily operating mode of HPP with base component. Unlimited daily regulation can be realized at supported the bottom (for example, on Zhigulevskaya HPP, that bottom is propped up by the Saratovskaya HPP) [3].

In a power system the week operating HPP mode usually realized together with daily regulation. This regulation type provides decrease power in the days off, forming the additional volume and its evacuation in the working days.

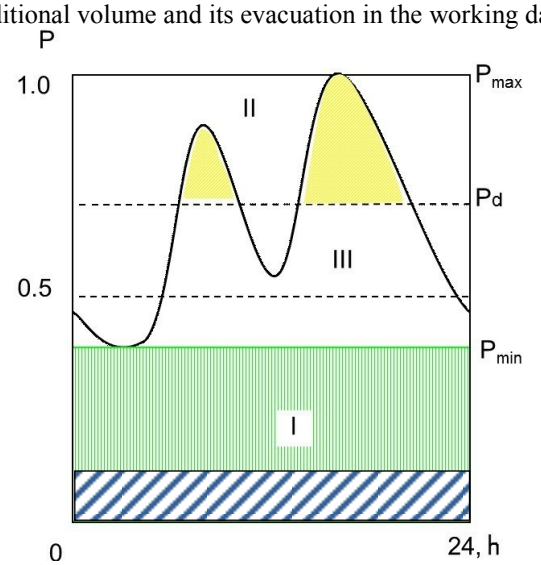

Fig. 1. Daily power production schedule: I - basis, II - peak, III - half peak

Therefore, there is a possibility of power increasing at these days.

In the annual section, the modes of HPP operation differ for different year seasons. Neither day nor week regulation is carried out during the flood. Increased water flow has used to fill the reservoir and to obtain the greatest power generation. In that case, fuel of the thermal power plants has saved and the energy has reduced. With a filled reservoir and excess water in the river, the HPP must operate around the clock with the total installed capacity in the basis of the load schedule. In that period the standby units are included to obtain the greatest energy production. In modern economic conditions and the allocation of generation in a separate type of economic activity, the criterion of fuel economy does not always work. Therefore, during the flood period, sometimes it is necessary to do escapades, which reduces the production of HPP. In low water periods of the year, daily regulation has carried out at HPP.

The management of HPP operation modes with annual flow regulation is usually carried out according to dispatch schedules. In an annual operating modes of HPP differ for different year seasons. In a high water neither daily, nor week regulation have not be spent. With high water approach the raised flow of water in the river is used for reservoir filling and increasing of power productions. At this case there is observed an economy of fuel on heat power plant and electric power depreciation. At the filled reservoir and surplus of water in the river HPP should work full installed capacity in basis power production schedule during round the clock. In this period for getting of the greatest energy from HPP the reserve units have joined. In modern economic conditions and generation allocation in a separate kind of economic activities, criterion of fuel economy does not always work at generating source choice. Therefore, in a high water period it is necessary to do the escapades that reduces HPP power production. In low water seasons of year HPP is spent the daily regulation.

The management of HPP operation modes at annual regulation spends under schedules representing a dependence of the reservoir volume from time. On the dispatch schedule three zones are represented: a safety zone with completely open spillways and full turbines capacity; a zone of the guaranteed water flow and a zone of the raised water flows. Dispatching schedules allow to define management strategy of HPP operation and facilitates making a correct decision.

B. Pumped storage power plant

Currently, the dominant position in the accumulate system market for large-scale power generation (over 96%) is occupied by pumped storage systems and, above all, pumped storage power plants. The total capacity of the pumped storage power plant in the world is over 150 GW. Agency IRENA forecasts an increase in the capacity of the PSPP to 325 GW by 2030 [4].

Pumped storage power plant (PSPP) and hydropower plant have the maneuverable properties of aggregations and

reservoirs for accumulation and energy redistribution that increase of the power system reliability, especially in the conditions of WPP and PVP the great share. Their operation mode dependences of equipment parameters, hydrological essences, reservoir volumes. In that case, the reservoir is an energy accumulator.

The pumped storage plants work in a pump mode as an electricity consumption, creating an additional load for the nuclear power plants and thermal power plants and decrease of gas turbine power unit loading in a power system. The pumped storage plants raise the reliability of power supply, carry out functions of capacity reserve and operate in the synchronous jack mode.

Creating PSPP project it is necessary to take into account the factor of uncertainty related to the water flow forecast [5, 6].

Uniqueness of PSPP consists not only in essential reduction of consumed fuel volumes and optimization of operating modes for basic power plants using organic fuel, but also in substantial increase of power system reliability. The technique has developed for research of energy-economic efficiency of PSPP participation in the power market regarding granting of regime and system services and reception of the greatest profit and the maximum system effects [7, 8].

C. Wind power plant operation modes

The most researches, modern technologies and real operation of wind power station (WPP) in the countries developing wind power have shown that receipt of WPP energy is enough predicted, and wind energy successfully sales in the energy markets. The average accuracy of power schedule forecast “for days forward” makes about 95% in Europe.

There are not unplanned and sharp inclusions/switching-off of all WPP since it represents group of generating sources and malfunction of all WPP is impossible in the same time. According to statistics, such factors as unpredictability of the energy production schedule, probability of transmission line failure or drop out of the large unit (some hundreds MW) of traditional power plant are considerably above than failure of WPP having the same capacity [9-10].

Operation experience of foreign WPP has shown that the energy system reserves are enough for indemnification of fluctuations in output in a case of wind energy share is about 20% in the general power balance. If the wind energy share is over 20% there have known approved actions for successful WPP integration into a power system.

Operation modes of autonomic WPP is directly connected with changing characteristics of a wind stream. Power production actually changes from zero to nominal power, however current voltage and frequency change within standard values in the presence of the monitoring and management system (Fig. 2).

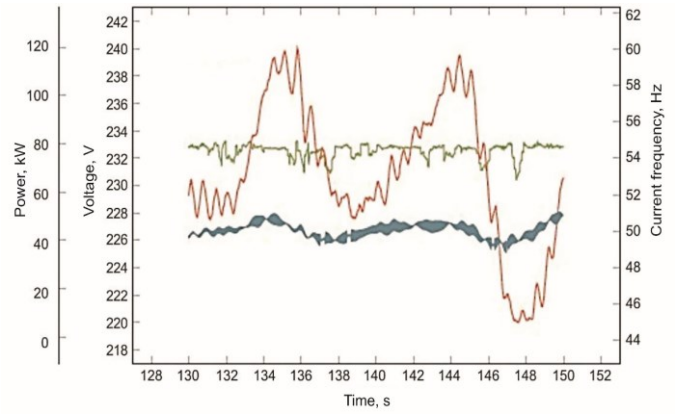

Fig. 2. Characteristics of WPP operation on short-term intervals

Nowadays, for reliability increase and decrease of capacity pulsations and current characteristics at WPP operation network it is possible to allocate next ways:

1. Integration of wind park by quantity wind power units for smoothing of territorial non-uniformity of wind power.
2. Association of autonomic WPP management in uniform «virtual wind park».
3. Increase of wind energy forecasting accuracy arrival for various time intervals.
4. Use of modern types of the equipment (generators) and energy transformation systems (power electronics) wind power unit (WPU), allowing to render system services and regulate pressure in a joining point of WPP to a power system [10-14].

The first way allows to reach following effects (the example of wind park in Germany):

a. Non-uniformity of WPP production on 10 minute intervals decreases from 65% (at WPU operation) to 5% (at 300 WPU operation) at the expense of wind distribution smoothing;
b. On 10 minute intervals of capacity fluctuation of such large wind park become comparable to casual fluctuations of load schedule. At 10% share of wind energy the necessary capacity reserve has to 2-4%;
c. On small time intervals (second) WPP capacity varies very slightly.

The second way of reliability increase allows to create the general management infrastructure in virtual wind park, considerably to lower capacity fluctuations for hours and daily intervals. So, integration 40 WPP in "uniform" wind park, located in the big territory in Germany, has allowed at the expense of decrease the forecast error and manufacture alignment to lower capacity fluctuations in 3-4 times [15, 16].

The third way connected with increase of wind energy forecasting accuracy arrival to WPU, is very important for correct and economic WPP participation in the energy markets. The forecast accuracy depends on the forecast

duration. Nowadays the mathematic modelling methods of output forecast are developed on the basis of statistic analysis of wind mode previous short-term characteristics, and also ways of wind measurement before WPU on various distance, placing a laser measuring instrument (LIDARa) on a gondola [17, 18].

The fourth way of WPP reliability in power system is connected with introduction of full-scale energy transformation systems in modern WPU using achievements of power electronics, including IGBT-transistors. At use of such system there are provided as control of electric current quality indicators, so the control of active and jet capacities. The scheme of monitoring and management such system is represented in the Fig. 3.

The example of WPP HornsRev (Germany) participation with modern WPU in a power system has shown in Fig. 4 the period from 0-00 to 8-00 o'clock in the morning with realization of balance functions and maintenance of reserve for frequency regulation.

Thus, modern WPU and WPP are capable to take part in the power system operation, including to power parameters system management.

D. Solar photovoltaic plants operation modes

Modern photovoltaic plants (PVP) are complete galvanic untied with a network as they connect to it through inverter plants executed on IGBT transistors (Fig. 5). Inverter plans carry out transformation of constant voltage to a three-phase sinusoidal alternating voltage. The addition power LC filters

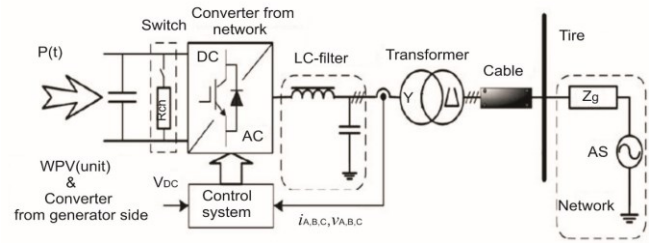

Fig. 3. The scheme of full-scale energy transformation of modern WPP (WPU SiemensSWT-2,3-93)

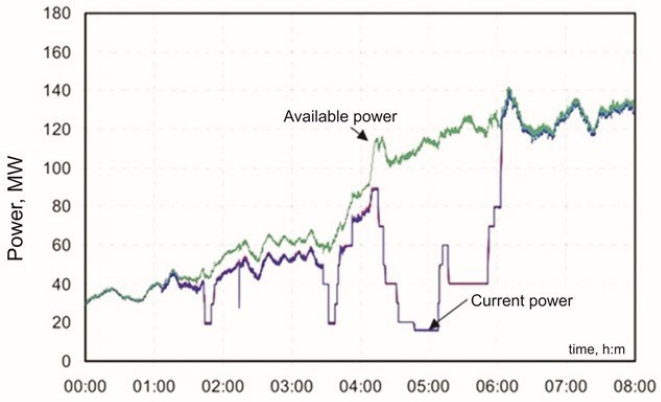

Fig. 4. An example of WPP HornsRev operating modes with realization of system services

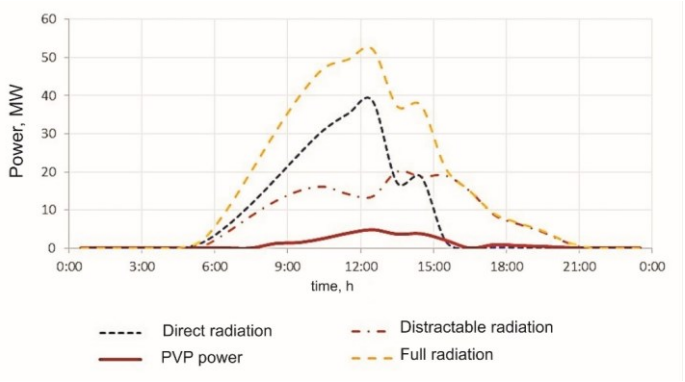

Fig. 5. Change of PVP capacity (PP_{VP} = 10 MW) during the day (Orenburg region, July, 9th, 2016)

have used for reception of ideal sinusoidal voltage, thus connection PVP to a distributive electric network is carried out through raising transformers. Consequently, the basic management of voltage, frequency and capacity of PVP has carried out in inverter plant [19, 20].

In the most cases, photovoltaic plant operates in parallel with a power system when it is frequency does not practically depend on the power plant operation. Therefore, PVP management system of inverter plant has applied to provide the set generation of active capacity at current value of frequency in a network.

PVP capacity depends on solar radiation intake, including the laws of the sun movement, the overcast and influences the established operating modes of a power system. In Fig. 5 it has shown the change of PVP capacity during the day depending on a solar energy arrival in the real overcast conditions.

Thus, development of PVP has variable character. It is necessary to underline on minute, ten-minute and sometimes and half-hour intervals of time the mode has accepted queasy stablished, so on these intervals power production has accepted by a constant value with some deviations. However, at sharp changes of weather condition non-stationarity it shows in the most degrees. Thus, the acceptance of operative-technological decisions is required.

There can be used the ways in the power system for decrease of PVP production instability, described above for WPP as change of wind and solar characteristics are similar.

In addition to the considered ways for decrease of PVP and WPP production instability there could use some more ways.

One of such ways for WPP and PVP has connected with possibilities of energy accumulation and capacity delivery in energy deficiency. Such accumulate systems (AS) can settle down at WPP or PVP and have commensurable capacity (hundred kW) and power consumption, and AS, connected to network substations, having unit capacities in tens and even hundreds MW.

E. *Energy complex operation modes*

Energy storage by hydroelectric reservoir is an effective solution for the accumulation of wind energy. It has proposed to accumulate the energy of the wind power plant using the reservoir of the hydropower plant by combining the WPP and HPP in the energy complex by common electrical and information connections. In Fig. 6 WPP and HPP connect by electrical lines to a common switchgear, from where energy is supplied to the consumer.

It is assumed that the WPP is located not far from the HPP and from the common load center. Therefore, the losses in the network have not taken into account in the calculations. In addition, power plants are connected to each other by information links through an automated control system. HPP provides smoothing and redistribution of variable output from WPP. HPP with a reservoir is an accumulating system for storing electric energy from WPP with the high efficiency of energy storage about 90% [21].

The functions of AS are represented in Fig. 7.

The AS allows to pass to the electric power production of new generation, provide availability of power to all consumers and create a basis for pure and stable power systems. Introduction AS allows to keep the energy developed by renewable energy sources objects and to use it in necessary daily time [22, 23].

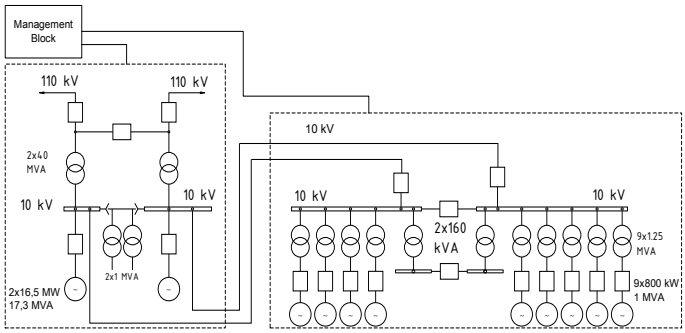

Fig. 6. Scheme of HPP-WPP communication and management

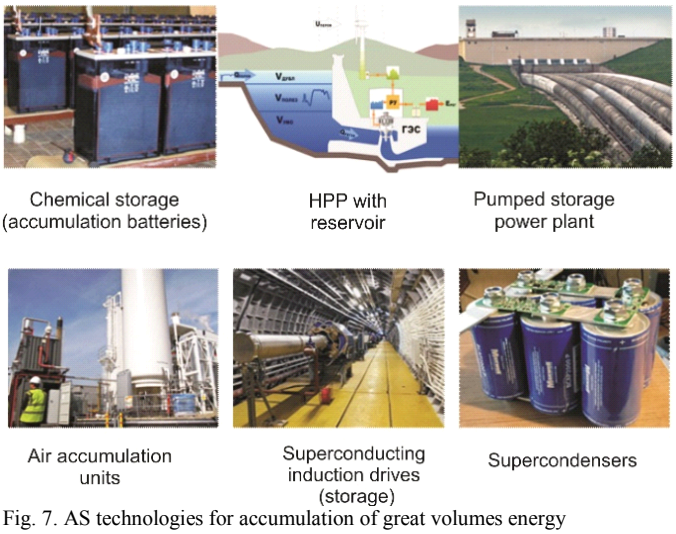

Fig. 7. AS technologies for accumulation of great volumes energy

V. Conclusions

1. The experience of foreign power plants with the most share of low-maneuverable power plants and renewable energy plants shows that the share of all types of highly mobile plants should be at least 25% of the total installed capacity of the power system.
2. For the organization of optimal and reliable operation of the energy system, the share of PSPP (taking into account their ability to carry out double regulation - both generation and load) should be 10 ... 12% [24].
3. The efficiency of hydraulic accumulation in power complexes with renewable energy sources is 92-95%. Another effect of such a power complex is to ensure guaranteed energy output from wind power plants or solar power plants at the required time intervals and predicted participation in covering the load schedule.
4. Specific fuel savings due to the introduction of the PSPP into the power system will be 0.16 ... 0.187 kg / (kW·h) [25].
5. The creation of an energy complex HPP-WPP can provide an increase in the regulation range by 20% and a guaranteed maximum power by 12% [26].

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