RIGA TECHNICAL UNIVERSITY

Department of Power and Electrical Engineering

Inga Zicmane

Power and electrical programme

(Ph. D. student card Nr. 911111240)

CONTROL OF HES OPERATING OF WATER CONDITIONS AND THEIR FORECASTING

Extended Abstract of Doctoral Thesis

Scientific supervisor
Dr. hab. sc. ing., Professor
Jekabs Barkans

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OVERVIEW

ACTUALITY OF THE WORK Hydro energy is the most utilized kind of renewable energy. Its serious disadvantage is however its dependence on the river waterflows, which are uncertain. Such uncertainty sometimes jeopardizes contracts on energy supply, planning the regimes of water reservoirs, working out the tariff. policy, defining the budgets of energy systems, planning investments connected with equipment renovation, and so on. The mentioned disadvantage could be considerably reduced if the situation would be predictable.

That is why forecasting of electricity production by hydro power is one of the most topical problems.

GOALS AND TASKS OF THE WORK The goal of the work is, resting upon the experience accumulated in the management of energy systems and HESs, to make clear the significance of the latter under the conditions of open market. Having ascertained that there was a need to improve the forecasting methods as far as the hydro energy production is concerned, it was necessary to verify the possibilities of such methods with the help of the energoinformatic discipline. Considering the data of observation over the Daugava river's flows as signals and applying mathematical methods, we had to find intrinsic properties of these flows - if any - which would allow for dealing with them as with determinate relationships. If such properties do exist, then our task is to find a factor of general character that is determining in this context.

SCIENTIFIC NOVELTY The traditional methods of research being dismissed, the observation data were treated with the methods adopted in the measuring technique. As a result, it was established that the world rivers' waterflows bear a cyclic character, with a definite periodicity and phase shifts peculiar to different regions.

The waterflow process consists of five various frequency components, each of its own character. Having noticed the global character of these peculiarities, one had to find a factor of the same globality that influences them.

It was revealed that the global factor influencing annual river waterflows is variations in the Solar intensity. Its spectrum basically coincides with the main components of this process. Since the spectra of Solar intensity are known and predictable (by NASA and artificial neuron networks' methods), to forecast river waterflows also becomes possible.

The facts mentioned above have not been yet known, and they are of great scientific and practical importance; they open new horizons in various fields of science, such as physics of atmosphere, geophysics, and astrophysics, in the framework of which nuances of relationships between the established facts should be examined.

RESEARCH METHODS AND TOOLS Acting in the interests of power industry and having set a goal of successful realization of the actual potential of hydro power generation, we had to abandon the application of traditional methods adopted for treatment of river waterflow data and to treat the observation data, as it is usually done in measuring technique. As a result, special hierarchical digital filters have been designed. Their purpose is to separate "good" signals and to minimize signal "noises".

Prior to that, there were found functions to be transformed into auxiliary ones, whose form would depend on the spectrum of the process. For low frequencies this would be an integral function of initial data, while in other cases - differential ones. Therefore methods of data integration and differentiation were employed.

After the analysis, which was performed with the help of auxiliary functions, the results had to be reverted to the original units. This was achieved by inverse mathematical transformations.

Apart from that, the probability theory methods were widely employed, e.g. those of correlation and regression analysis, in order to reveal similarity of the functions and elucidate their genesis.

Owing to the new analytical methods applied in the course of solving the mentioned task, yet unknown peculiarities of riverflows have been discovered, which gives rise to new forecasting possibilities and might become a stimulus for developing various fields of science.

VERIFICATION OF THE RESULTS To estimate the effectiveness of the method, long-term observation data on 45 rivers of different continents average been used. The found relationships were verified in retrospective. In such a way the effectiveness of the use of determinate relationships was substantiated.

PRACTICAL APPLICABILITY OF THE RESULTS The relationships established in the course of studies were presented to the operative services of LATVENERGO in order to realize them in practice for forecasting the electricity production by HESs.

A wider implementation will be expected based on publications of the results of the present work. In Russia, these are published in "Electric Stations" journal, 2003, N9. On the global scale, this will be possible after a monograph's publishing in English, which is envisaged to be done in 2005).

LIST OF PUBLICATIONS The work is presented in 13 publications.

STRUCTURE OF THE THESIS The thesis consists of 9 sections, introduction and conclusion. It also contains references to 70 literature sources, 62 figures, 6 tables, 2 appendices, and is written in 192 pages.

INTRODUCTION (REVIEW OF LITERATURE, GOALS AND TASKS OF THE RESEARCH)

When analyzing the methods of control over hydro electric stations in the first sections of the work, it should be stated that such a control is based on the forecasting of electricity production. The goal of the work is to work out scientifically substantiated methods of forecasting the HES production and to focus on the cyclic behaviour of the process.

The first investigator to notice this phenomenon was a German scientist E.Briickner (1862-1927), who in 1890 published the data on the 30-year cycles in the development of Alpian glaciers. The results of his work evidence that Bruckner's cycle is the third harmonic of a 88-year cycle.

Although the data on Bruckner's cycles could be found in all encyclopedias, until very recently it has not come to mind to verify them by the data on river flows, despite the fact that scientific works devoted to this problem are numerous. This is confirmed by references to 470 scientific publications. There are publications containing data on the cyclic character of weather conditions concerning the temperatures, ocean streams, stratosphere winds, etc. However up to the present time this point of view has been estimated as discussable. The confirmation of this is found in the book by W.J. Burrough "Weather cycles - real or imaginary" (a Cambridge University's publication of 2003). This book also does not consider the problems of river flows.

With regard to the eastern slope of the Baltic Sea basin, the only scientist who paid attention to the cycles of rivers' and lakes' inflows in this region was Dr. sc. L. Glasacheva, a lecturer from the Latvian University. She considered these cycles in total, without isolating the components of the process.

As a result, only individual hints were used as the basis for the work, which however turned out to be of great significance.

While solving the problem, the data on the world river flows have been employed, which were published in UNESKO proceedings.

Concerning the factor influencing the mentioned above global peculiarities of riverflows, the data on Solar intensity variations in Wolfs numbers and geomagnetic index units have been used starting from 18-th and 19-th century, respectively.

The task of the work was to study the world's riverflows so that their intrinsic features could be established, which, being verified, would help to find the factor influencing these features. With orientation to the methods of research adopted in the energy industry.

2. OPTIMISATION OF HES OPERATION

The functioning of a power system minimize expenses connected with energy production.

The methods of optimisation differ depending on what is to be optimized. If the organization aspect is assumed constant, we can proceed with minimization of variable expenses.

If the number of HESs in a power system is large, their positions in the diagram is depending on the riverflows. In turn, on this positions the utilized power depends. The higher the diagram position is, the greater the possible HES power utilization.

In the course of optimisation the available water amount should be known on the weekly and monthly scale. Therefore one of the main conditions for HES utilization is forecasting of hydro energy production.

In the case of cascade operation the total power produced by several HESs is depending on the volume of water reservoirs and on the possibilities of forecasting the filling these reservoirs.

The plans for optimal utilization of water reservoirs are defined using methods of operational calculus, with uniform or non-uniform boundary conditions and the output data in the determinate, random, and indeterminate forms. When defining the regimes for water reservoirs, in the mathematical algorithms we should orient ourselves to the convex programming. The methods of dynamical programming could also be used.

3. ECONOMIC SUBSTANTIATION OF FORECASTING THE HES OPERATION UNDER MARKET CONDITIONS

The situation of the market is influenced also by the terms of energy purchase transactions. Here long-term and short-term transactions and real-time consumption. Long-term transactions are concluded in the cases when the intended supply and consumption are to be realized in a long run and with sufficient reliability. If this can be done in a short run, the short-term transactions are conducted. The remaining consumption is provided based on the real time tariffs (spot market).

The long-term purchases give to power stations a confidence that they can compete on the market, which means certain discounts, that is, a benefit for both sides. Thus unprecise forecasting becomes a burden on hydro energy generation.

Therefore investigation that might improve the precision of waterflow forecasting is desirable and topical.

The cost of hydro electroenergy is dependent on the position of a HES in the load schedule. In this schedule HESs are substituted for other power stations, which would work if there were no such hydro plants.

In the periods of high water HESs position are found in the lower part of the schedule, replacing thermoelectric stations (TESs) and nuclear electric stations.

This means that the HES prices are determined by the latter two kinds of electric stations, with a certain discount owing to the competition. When water falls, the HESs move to the upper part of the schedule, substituting for CES, combined cycle stations, and, finally, gas-turbine electric stations, with corresponding increase in prices. As a result, at lower water a decrease in the HES income is compensated, to a certain extent, by higher prices of hydro energy.

If HESs are employed on the energy market a new situation arises, which can be characterized by the necessity to ensure the maximum income under the conditions of competition.

The prime cost of HES electroenergy *Ci* contains maintenance expenses *A* which, in turn, include also investments related to the year of pay-back:

$$C_1 = \frac{A}{a\bar{Q}}, \qquad (3.1)$$

where $\bar{Q}$ is the average annual waterflow in the pay-back period, m /s;

a is a coefficient, (m^3/s) / kWh.

The prime cost sensitivity to the waterflow is: $d\,C_1 / d\,Q = A / a\,Q^2$.

Under the market conditions the energy cost is determined by the real competition.

In practice, the load schedule appears in the market with price zones.

Using concrete analytical connections, this paper shows, that the sensitivity of market prices of electroenergy toriverflows is:

$$D\,C_2 / dQ = C_{max} / (\,b + d\,Q + g\,Q^2\,)^2\,(\,d + 2\,g\,Q\,). \qquad (3.2.)$$

4. SIGNIFICANCE OF THE FORECASTING OF RIVERFLOWS IN THE ENERGY INDUSTRY

To forecast the annual electricity production by hydro electric stations it is necessary to know the riverflow relationships.

The chain of the corresponding processes and their mutual relations are complicated; in particular, it is so since separate processes of this chain refer to different branches of science that are difficult to co-ordinate. Therefore the task of the work was:

1) to find out whether or not the waterflow processes incorporate some important intrinsic properties;
2) if such properties do exist, then to verify them on the global scale;
3) if it is established that these properties are of global character, then to find the factor that is determining for such processes and further to use it for the needs of forecasting.

As a result of such investigation, the forecasting procedure will be carried out without intermediate operations, with the relationship only remained between the determining factor and the energy generation (see Fig. 4.1); in such a way the primary forecasting is transformed into a simple in use formal procedure relying upon input database and mathematical programming methods.

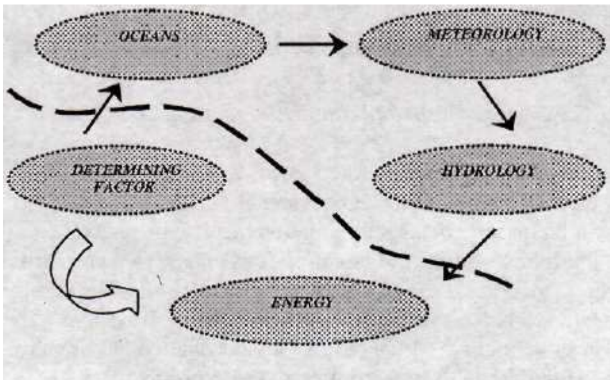

Fig. 4.1. Intermediate links

In the analysis of a waterflow process the initial data - those of observation - are used as digital signals treated in a manner similar to that existing in electric measuring technique for signal treatment. The good signal in this case will be a set of values that can be properly described.

The job was started using analysis of internal peculiarity of Daugava's waterflow. For this purpose there were used annual average waterflows, q'(t) since 1881 (see Fig. 4.2).

One of the criteria for the choice among the analytical methods is simplification of the research work and visualization of its results. As known, for these purposes various auxiliary functions are employed. Initial processes are thus transformed into auxiliary functions which are then used for the analysis. The results of the analysis are converted again to the original units so that the research work can be continued.

Judging by the process depicted in Fig. 4.2, we are dealing with a process having a determined spectrum. The spectrum can have components of different frequency. The low-frequency components should be cleared up from separate pulse-like observation effects by smoothing them. This can be achieved through integration of the original function process.

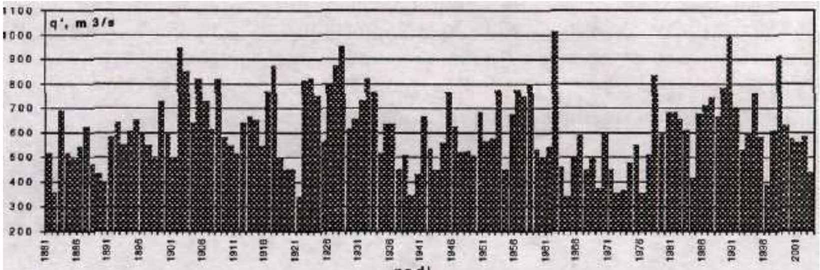

Fig. 4.2. Daugava's annual waterflow data of 1881 – 2003

The integral of the process is of periodical character, which can be described analytically, therefore it contains the "good signal". The semi-period length is 44 years. The observation period contains three incomplete semi-periods. From Fig. 4.5 it follows that the semi-periods possess approximately equal amplitudes that correspond to the two-year waterflow norm. The semi-periods are of practically identical shape, symmetrical relative to the time axis. Therefore the curve of the process contains odd canonical (integer-valued) harmonics which are found applying the Fourier analysis according to the expression:

$$F(t) = A_0 + A_1 \sin(wt + \varphi_1) + A_2 \sin(2wt + \varphi_2) + A_3 \sin(3wt + \varphi_3) + \\ + A_{km} \sin(kwt + \varphi_k), \qquad (4.1.)$$

where A_0, A_{km} are a free term and harmonic amplitudes, respectively;
φ is the angle characterizing the shift of a higher harmonic.

The free term is determined by the beginning time of integration. If this time coincides with an extremum of the integral function, then the free term will be maximum and the integral curve will be unilateral as to the ordinate zero. In other cases the ordinate might be of value - from zero to the extremum. For visuality sake, the time axis is to be shifted by the ordinate value, which is equal to the free term.

For better clarity of the result, the average shape of the process semi-periods was defined based on their absolute values. The result is displayed in Fig.4.3., where the harmonics are simultaneously shown whose sum can be expressed as:

$$F(t) = -163{,}120 + 1225{,}335 \sin(wt + 200{,}610) + 565{,}271 \sin(3wt + 45{,}934) + \\ 35{,}938 \sin(5wt + 30{,}298). \qquad (4.2..)$$

Further from the natural process there should be excluded the components of determinate process. For this, the approximation should be reverted into natural values, which is achieved by its differentiation:

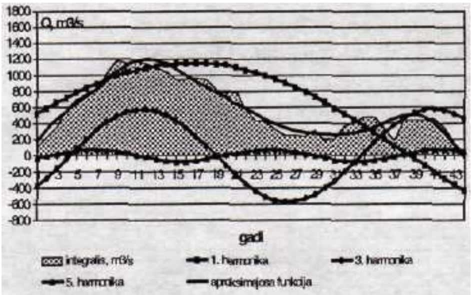

Fig. 4.3. Spectral analysis of average shape of three semi-periods

$$Q / d t = q (t). \qquad (4.3..)$$

Having excluded it from the natural function,

$$q' = q_{max} (t) - q_{ap} (t), \quad (4.4.)$$

one obtains the first "remainder" of the approximation.

In the first remainder auxiliary noninteger-valued (non-canonical) harmonics can be expressed.

The isolated harmonic is stationary and it embraces all the time of observations, which allows Fourier's transformation to be applied.

After the first noninteger-valued harmonic's inclusion into the determinate function and its exclusion from the natural process, a second "remainder" forms that cannot be considered stationary any more, since it contains variable in time cyclic components. Such being the case, the log Fourier transformation is applied.

Taking into account that the amplitudes of these frequencies are limited, we can restrict our attention to its first harmonics.

When analyzing the integral of Daugava's flow deviations it has been established that the second remainder contains two differing frequencies. One of them corresponds to the first semi-period, while the second and the third semi-periods contain the total harmonic.

After these harmonics' inclusion in the determinate set a third "remainder" is left, which contains two components: rare high-amplitude deviations - we will call them "overshoots", and non-stationary process of limited amplitude.

As to the reduction in the uncertainty degree for waterflow function, one can compare the standard deviations of the integral function a for the natural process and the first remainder, m^3/s:

$$\sigma_{s\bar{a}k.} = 6\,9\,9{,}371,$$
$$\sigma_{atl1.} = 41{,}533,$$

where $\sigma_{s\bar{a}k.}$ is the standard function deviations for the natural process;
σ_{atl1} *is* the standard function deviations for the first remainder.

This evidences that the forecasting accuracy can be noticeably better already at this point.

Complementary frequencies are taken into account by repeated application of the above described mathematical methods. Having isolated the first one, we obtain the second "remainder" and if it is done for the second one then the third "remainder" will be obtained. The third integral "remainder's" standard deviation for the Daugava σ is 163,096.

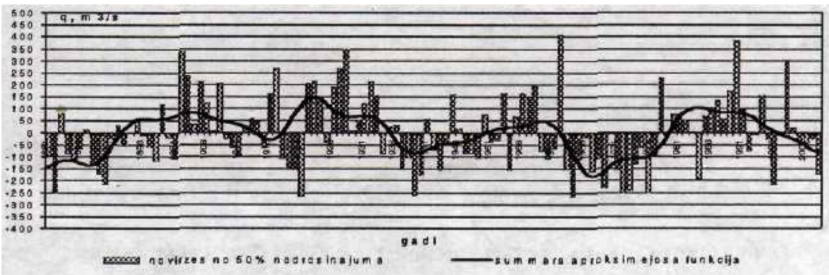

Fig. 4.15. Waterflow deviations from the many-year average value and the summary approximating curve

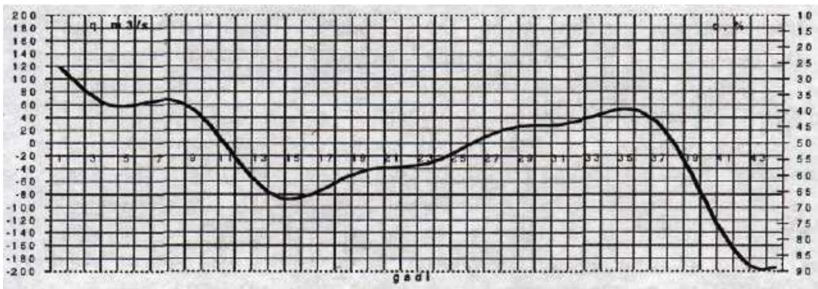

Fig. 4.16. The derivative of the summarized approximation function of the integral cycle as a waterflow deviation norm within the cycle and its values expressed in reliability terms

The derivative of the resultant low-frequency integral approximation function that can be used for the needs of forecasting is shown in Fig.4.4.. Each of the flow values seen in this curve corresponds to the supply determined for many years. For this purpose an additional supply reliability scale (Fig.4.5.). Every year possesses its own level of supply, which can vary in a wide limits. It is easy to verify that there are years for which as a base level 80% many-year supply should be considered, while in another time interval this can correspond to the 20% many-year supply.

5. MATHEMATICAL INVESTIGATION OF RIVER FLOWS

The analysis of Daugava's yearly flows enables us to put forward a hypothesis that other world's riverflows, with due consideration for regional specifics, may possess similar properties. To verify the hypothesis, an analytical method was required, with the help of which it would be possible to treat a large data set, to isolate good signals and minimize noise.

The number of analytical operations in this case is large and they should be qualified in sets depending on the goals to be reached and taking into account the peculiarities ol a pnenomenon under consideration.

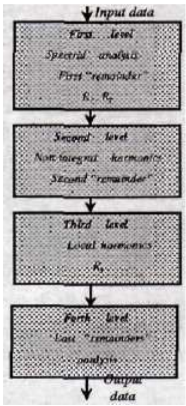

Fig. 5.1. The structure of a fourth level mathematical procedure

Taking into account that the output data are treated as signals, we should orient ourselves to mathematical procedures whith functions of digital filters. The specificity of the problem under consideration required that an original system of this method be developed. It should have four hierarchical levels, Fig.5.1.

The first level isolates low-frequency integer-valued (canonical) harmonics of the integral function of waterflow deviations, defines their determinate sum, its derivative and subtracts it from the original data of natural process; in such a way the first "remainder" of the process is found, for which the integral function is found again.

The second level isolates noninteger-valued harmonics and the result of calculations gives the second "remainder" of the process.

The third level isolates local harmonics, which results in obtaining of the third "remainder" of the process.

The fourth level is meant for analyzing the third "remainder". This layer isolates the basic process of this remainder's non-stationary component, as well as isolates the rare high-amplitude variations, and isolates the final "remainder" of the process, which possesses probabilistic character but small weight.

The investigation can be realized *with interactive elements of image selection and with methods of automatic calculations.*

The first hierarchical level algorithm is shown in Fig. 5.2. The internal structure of the filter is as follows.

Unit 1. The integral function *Q* is obtained.

Unit 2. Randomly chosen in pairs time intervals *t* are accepted.

Unit 3. For the fragments of integral function that correspond to the mentioned time intervals the correlation coefficients are determined.

Unit 4. The interval *At* is incremented by δt, and for this interval the correlation coefficient is determined again.

If some time period *T*, e.g. 88 years, possesses clearly expressed maximum of the correlation coefficient, this evidences that the function's fragments are similar and that in the process there is a component of a periodical function.

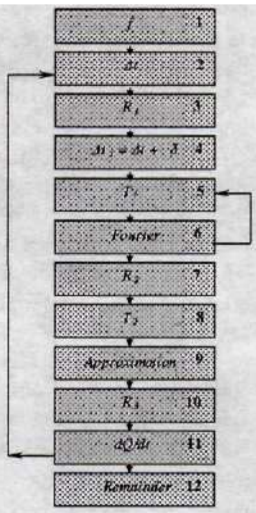

Fig. 5.2. The structure of the first hierarchical level

Unit 5. Correlation coefficients are compared for all comparable time intervals and a period T_1 is isolated that corresponds to the maximum correlation coefficient

Unit 6. Assuming period T_1 as a first approximation, spectral analysis of the integral function is performed using Fourier series. Since the function is practically symmetrical, sometimes the analysis might be limited by nonin teger- valued harmonics. Usually, harmonics 1, 3 and 5 are significant, with the first and third ones being commensurate.

The first harmonic corresponds to a centenary cycle, since its period is close to 90 years. The third harmonic corresponds to a 30-year cycle, which in the literature is known as Bruckner's cycle. The fifth harmonic corresponds to 18 years. The higher harmonics could be neglected.

The comparison forms a relationship that further will be used for the determinate component of the process.

Unit 7. The first approximation is compared with the integral function characterized with correlation coefficient R_2. This unit is used when correcting the first harmonic's period, and it performs also the functions of units 3-7.

Unit 8. In this unit the harmonic analysis is carried out for various values of period T embracing the first approximation by correcting period T_2.

Unit 9. The approximation corresponding to T_2 is obtained.

Unit 10. The approximation is compared with the integral function; here R_3 is obtained.

Unit 11. The integral function is returned to the original values by its differentiation. The correspondence of original function *q(t)* to the natural data series is characterized with correlation coefficient R_4.

Unit 12. Subtracting *q(t)* from the natural process, the first data remainder is obtained.

6. INVESTIGATION INTO THE WORLD'S RIVERFLOWS

The Daugava river as well as other objects of the Baltic Sea eastern inclination, with their quasi-periodical water inflow peculiarities cannot pretend to be of importance on the global scale. Therefore it is actual to investigate this peculiarity in its wider spatial distribution, which would turn to be of great theoretical and practical significance.

Based on UNESCO data on the most significant world's riverfiows, with the help of digital filters the flows of almost 50 rivers pertaining to different continents have been analyzed.

The analysis has confirmed that practically all rivers' flows possess quasi-periodical character. The duration of a semi-period is 44 years. The forms of the process are determined by its harmonical composition. For many rivers the waterflow process contains odd harmonics, mostly the first and the third ones. For some others it is typical to have paired harmonics as well (the second and the fourth ones). The coefficient of correlation with regard to the natural process for Fourier's series sum reaches an excessive value of 0.8 - 0.9, which is indicative of the degree of approximation precision.

The flows of all rivers where anthropogenic factors are mostly absent possess a cyclic character with a 44-year semi-period of integral function deviation, the harmonic phases of which are mutually shifted by definite angles of regional character.

Investigations into the peculiarities of world's riverflows testify that the periodical process phases for the rivers of different regions are mutually shifted by a definite angle. As the phase reference coordinate the Baltic's flow is adopted. From this point of view the rivers are divided into four groups whose phases differ by approximately 90°.

Based on the analysis performed, the phase maps are built for European and world's overflows (Fig. 6.1).

The first group contains the rivers whose phases differ only slightly on the Daugava's flow phase (see Table 6.1). To this group belong the rivers of the slope of the Baltic Sea basin, from Sev. Dvina and Neva to Niemen. Apart from those, this group includes also Colorado un Missouri (USA), Rio Grande (Mexico), Sao Francisku (Brazil), Niger (Africa), Rhone (France) and Angara (Russia).

The only factor that is common for the above listed rivers is that they flow on the mountainous territories, which can be clearly seen on the global physical map.

In the Middle Europe, the rivers belong to the second group (Vistula, Elbe). In this group alsp Russian rivers are found (Dnieper, Volga, Oka, Kama, Ob, Yenisei, Lena).

The third group contains South Europa's rivers that flow in the parallel direction (Danube, Po, Ebro), the Asian unidirectional rivers (Yangtze, Hwangho, Amur), and the Indian river Indus.

Table 6.1. Grouping of rivers by waterflow phases

Group 1	Group 2	Group 3	Group 4
Angara	Vistula	Danube	Congo
Sev. Dvina	Elbe	Po	Nile
Neva	Dnieper	Ebro	Parana
Niemen	Volga	Yangtze	Amazon
Daugava	Oka	Hwang Ho	La-Plata
Rhone	Kama	Amur	Orinoco
Missouri	Oba	Indus	Mississippi
Colorado	Yenisei	Glomma	Colombia
Murrey	Lena		Saint. Lawrence
Sao Francisku	Vuoksa		
Rio Grande	Keme		
Niger	Kymi		
Lule			
Muonioalven			

The African rivers Congo and Nile as well as American rivers Parana, Amazon, La-Plata, Orinoco, Mississippi, Colombo and the Saint Lawrence river occupy Group 4.

The fact that the world's riverflows possess approximately the same cyclic behaviour allows for a conclusion that there should be a common factor influencing this behaviour, which is to be found.

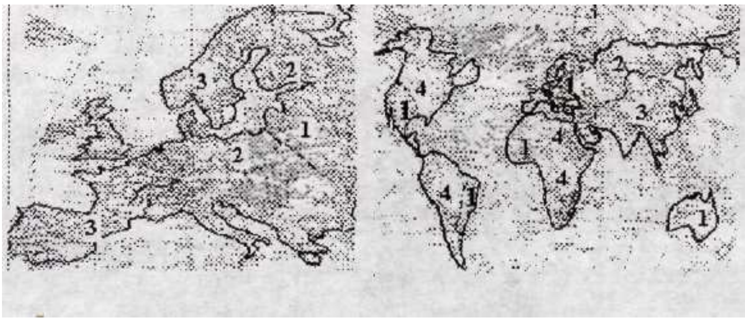

Fig. 6.1. Phase maps of the world's riverflows

7. INVESTIGATION INTO THE CAUSES OF LOW-FREQUENCY PROCESSES

The process of Solar intensity variations consists of two components, see Fig. 7.1. *First* of them is a high-frequency process, whose period lasts 11.1 years on the average. In the time of observation this period slightly vary within the range from 9 to 14 years. The duration of the period depends on the maximum intensity. The higher this maximum intensity is, the shorter the period.

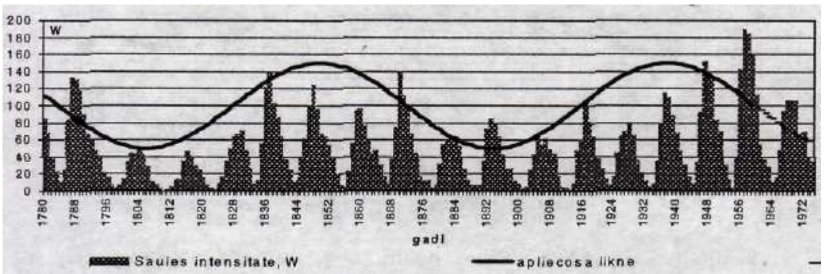

Fig. 7.1. The characteristic curve of the maximum Solar intensity for two centenaries

The growth in the activity usually occurs within 4-5 years, while its decline - within 6-7 years. It is natural that at variations in the duration of the total period these numbers vary as well. For practical needs we should have a notion about the so-called 11-year period's forms. With this purpose in mind the average period curves

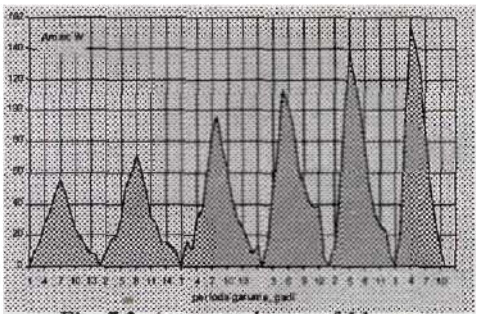

Fig. 7.2. Average shapes of 11-year periods of Solar intensity

have been defined, which are graduated in maximum intensities. The results are shown in Fig. 7.2.

Second component of Solar intensity variations is connected with variations in the maximum intensity values. In Fig.7.1 the cyclic behaviour of the W_{max} value is clearly seen. On Solar 11-year cycles there are superimposed the maximum intensity cycles with a hundred-year.

Having built the approximating curve for the maximum Solar intensity observed in 1893-1974 (the first harmonic) and matching the abscissa axis of this curve with the ordinate axis so that it is equal to the free term of Fourier's series, we then compare it with the integral curve of Daugava flows' deviations, Fig. 7.3.

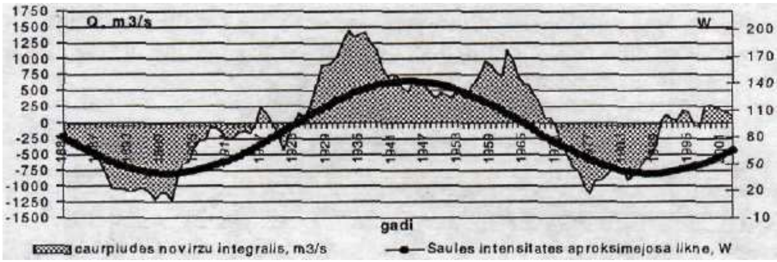

Fig. 7.3. Comparison of the characteristic curve of the maximum Solar intensity in 1893-1974 with the integral curve of Daugava flow deviations

While looking at Fig.7.3 one should notice that it is of qualitatively similar nature. Therefore one of these processes is the cause and the second - the consequences. It should be stated that the integral function of Daugava waterflow deviations are determined by variations in the maximum Solar intensity. A question now arises: is it possible to forecast waterflows of other rivers based on the parameter W_{max} ? Obviously it is, if we correspondingly shift the processes by phase.

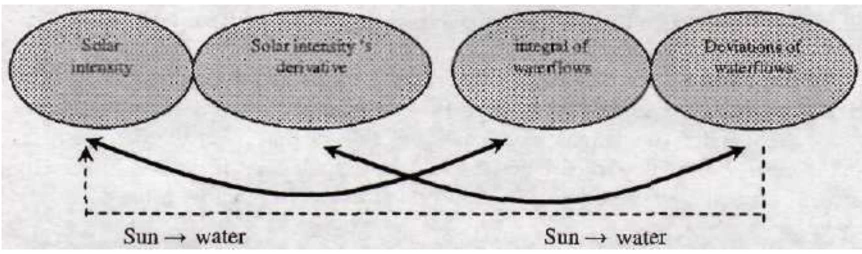

Fig. 7.4. Links between waterflows and Solar intensity

The results obtained evidence that we have succeeded in fulfilling the task formulated at the beginning of the work: to find direct links between the annual riverfiows and the factors that influence them.

It is established that *the factor determining waterflows* is *the process of Solar intensity variations, since the flow integral is similar to the function of the first harmonic of Solar maximum activity:*

$$Q_1(t) \quad f(W(t) + a, \qquad (7.3)$$

where Q_1 is the fundamental harmonic of the flow, m^3/s;

a is the flow phase.

The relationship between.the Solar intensity and the waterflow is shown in Fig. 7.4.

From the above it follows that one of the most important elements of forecasting riverfiows is Sun observation, the data of which should be easily accessible. The function of the natural value of Solar intensity is similar to the integral of waterflow deviations, while its first derivative - to the deviations of waterflow second remainder.

8. POSSIBILITIES OF FORECASTING THE HIGH-FREQUENCY WATERFLOW PROCESSES

The main feature of the annual overflow "remainder" is its frequency, whose density distribution is shown in Fig. 4.16. The spectrum of this frequency is commensurable with that for the so-called 11-year cycle of Solar intensity. To gain a notion about the component of the Solar intensity process, one has to obtain its numerical characteristics.

When forecasting the Sun activity by its extremum values, the information on all the other data can be derived from the average forms of 11-year periods (see Fig. 7.2).

Figure 8.1 shows factual 11-year cycles (a) made coincident with their derivative (b) and the values of Daugava flow "remainder" (c). From this it follows that the "remainder" deviations practically coincide in time with the derivative of Solar intensity. The signs of the derivative and "remainder" deviations practically coincide. If based on the average deviations, this fact can be employed to forecast the "remainder".

When studying the waterflow "remainder" it can be established that sometimes spontaneous large positive and negative changes in deviations differ from those in other years. In such cases we are dealing with overshoots.

From Fig. 8.1 it follows that overshoots (marked with dots) also obey definite laws. The fact is that such overshoots occur in the years when the signs of the Solar intensity derivative are changing. When its sign changes from negative to positive, the overshoot is negative, while at the change of derivative from positive to negative the overshoot is positive (an exclusion is the year of 1962, when the sign change occurred in the opposite direction).

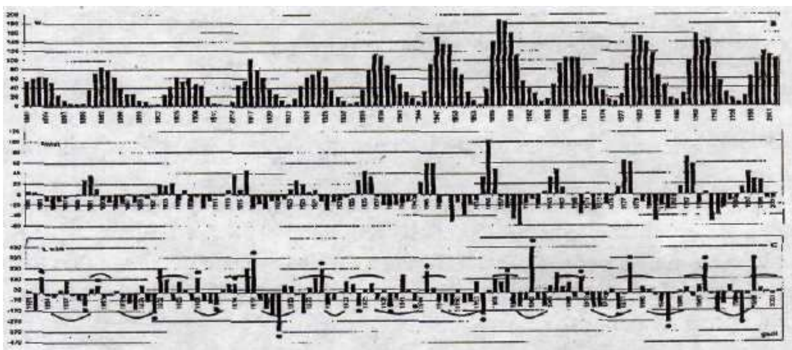

Fig. 8.1. Waterflow "remainder" process against the 11-year Solar intensity cycle: a) Solar intensity; b) intensity derivative; c) "remainder" of deviations

When analyzing the third remainder of deviations without taking into account overshoots, the average values of positive and negative deviations were obtained. Subtracting these values from the deviations of the third remainder, we obtain a corrected final remainder (see Fig. 8.2). Its positive and negative deviations (without "overshoots") are almost half as large as the initial deviations, which is tells about the precision of forecasting. It can be estimated based on the distribution density, which corresponds to the 4-th "remainder" values. The standard deviations of the 4 -th "remainder" ($\sigma_{r\,em\,4}$ = 63) are half as large as the 3-th "remainder" ($\sigma_{r\,em\,3}$ = 126).

The time of overshooting can be forecast with a minor uncertainty. The amplitude of these overshoots is defined as an average value, with positive overshoots being 217 m^3/sek and negative ones -178 m^3/sek.

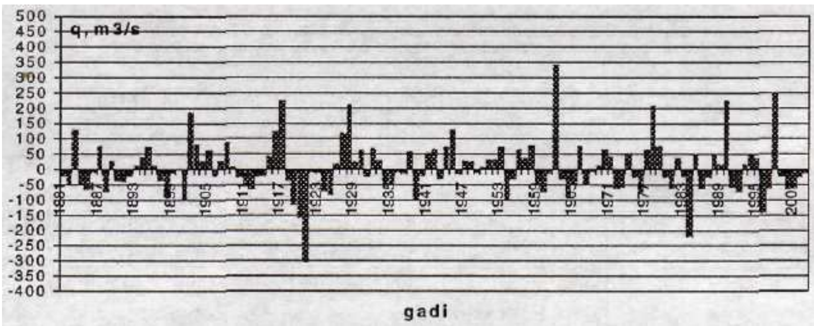

Fig. 8.2. Daugava's waterflowfourth "remainder"

To the final "remainder" therefore corresponds a non-stationary process that is of small specific weight. To. analyze it, a wavelet transformation (VT) can be employed. The use of the wavelet transformation for analyzing the "remainders" of waterflow processes can give in the future additional information.

9. FORECASTING OF THE MONTHLY WATERFLOWS

Of importance are scientifically substantiated monthly forecasts of HESs generation. These are necessary for the conclusion of concrete contracts on monthly energy supply, the planning of equipment repair schedules and the control of power systems' operation.

The necessary relations can be established based on the corresponding coefficients (see Fig. 9.1 and Table 9.1). Thus, knowing the data on the current month we can reliably forecast the waterflows for ten from twelve months.

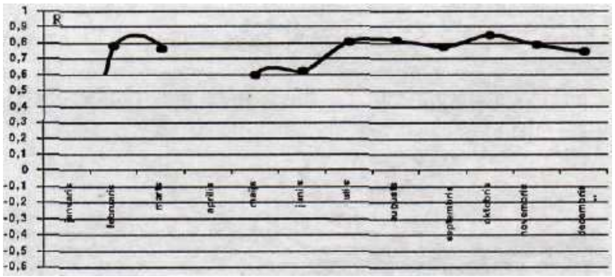

Fig. 9.1. Correlation coefficients between the current and the following months' waterflows

Table 9.1. Correlation coefficients and regression equations

month	correlation coefficients for forecasting the		regression equations for forecasting the
	next month	month after the next	next month
January	-0.284	0.410	
February	**0.780**	0.286	$Q_2=0.8299Q_1+20.96$
March	**0.762**	**0.693**	$Q_2=1.3245Q_1+131.49$
April	-0.229	-0.189	
May	**0.599**	-0.364	$Q_2=0.2102Q_1+496.92$
June	**0.622**	0.359	$Q_2=0.1588Q_1+249.84$
July	**0.807**	0.254	$Q_2=0.4725Q_1+74.654$
August	**0.816**	**0.676**	$Q_2=0.8116Q_1+27.481$
September	**0.772**	0.568	$Q_2=0.8285Q_1+70.23$
October	**0.851**	**0.762**	$Q_2=1.2548Q_1+29.036$
November	**0.785**	**0.680**	$Q_2=0.6579Q_1+196.38$
December	**0.744**	**0.686**	$Q_2=0.5924Q_1+150.47$

The waterflow is predicted based on the regression equation, (Fig. 9.2.):

$$Q_2 = Q_0 + b\,Q_1 \qquad (9.1.)$$

where Q_2 is the forecasted waterflow, m^3/s;
Q_0 is the free term, m /s;
Q_1 is the current waterflow, m^3/s;
b is the regression coefficient,

The probabilities of forecasts can be defined by the distribution density histograms (Fig. 9.3.) where on the abscisa axis the deviations of the waterflow boundary values from the regression smoothing are plotted.

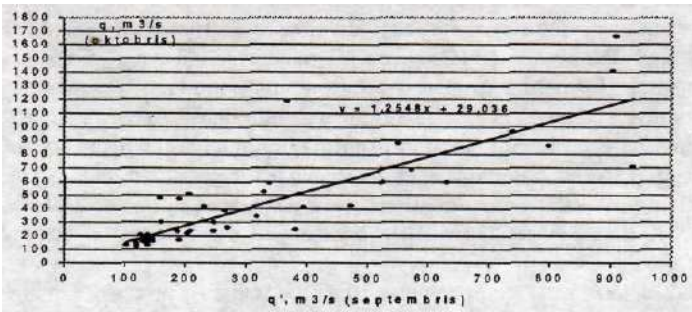

Fig. 9.2. R egression relation between the previous and the following months (September, October)

The method workout out for the monthly waterflow forecasting is based on the probability theory. In the case of a non-stationary situation when the circumstances change abruptly, similar patterns should be found for the needs of forecasting.

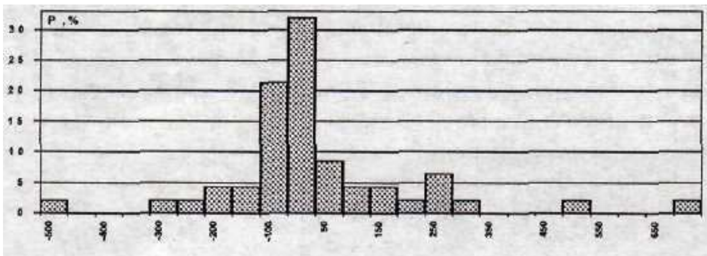

Fig. 9.3. Waterflow deviations from regression

CONCLUSIONS

1. Analysis of the methods for control over the operating conditions of power systems and HESs evidences that the task of raising the precision of hydro electroenergy production forecasts is of great theoretical and practical importance.
2. Data of investigations of river's water flow were analyzed, using subsidiary functions of it's transmissions. This gave a possibility to make the analysis more visual.
3. In the present work the riverflow observation data have been analysed by transforming them into some auxiliary functions, which provided good visuality of the analysis, based on Fourier's transformation and Fourier's log transformation. In the determinate waterflow approximation the canonical and non-canonical stationary and non-stationary harmonics were included. After subtracting the determinate function from the initial data, the results of analysis were reverted to the original values applying inverse transformations by their differentiation. All the transformations were embedded into specially designed four-level hierarchical structures of processing of data, based on the program package.
4. After the determinate components from the natural process having been subtracted, a "remainder" with a small specific weight and of random character is left, which makes it possible to raise approximately five times the precision of forecasting by performing it separately for different spectral components.
5. The verification of the global waterflow properties based on observation data for 45 world's rivers confirms that all these riverflows, with their regional phase differences, possess similar character;
6. It is found that the behaviour of riverflows as time functions corresponds to the behaviour of Solar intensity changes, both in the low-frequency and high-frequency spectral part.
7. In die work, methods for forecasting monthly Daugava's waterflows have been developed based on the probability theory.
8. Ten months of a year the waterflow of the next month can be predicted, with a definite degree of reliability, based on the current month's waterflow, applying a regression equation as the relationship between these values.

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