MINISTRY OF ECONOMY OF SLOVAK REPUBLIC

SLOVENSKÉ ELEKTRÁRNE, a.s.

SLOVAK COMMITTEE OF WORLD ENERGY COUNCIL

WORKSHOP ON THE ROLE OF ENHANCEMENT OF UTILIZATION OF PRIMARY AND SECONDARY HYDRO POTENTIAL IN THE CONTEXT OF ENVIRONMENTAL PROTECTION

Bratislava (Slovakia), 13 - 15 May 1997

I &

Part II.

We regret that some of the pages in this report may not be up to the proper legibility standards, even though the best possible copy was used for scanning

Use of a Primary and a Secondary Hydroenergetic Potential of the Slovak Republic for Electric Energy Production and Its Impact on Environment

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Utilization of hydroenergetic potential to acquire energy belongs to one of the oldest energy resources of a humankind. This resource has kept its importance in the world power balance up to now and also its share in an electric energy production as the noblest form of energy in a world balance of energy resources.

According to [1], the hydroenergetic potential shares in about 18.5%, the same as a power energy, in this balance. Only coal - 42.5%, shares in a larger portion in covering electric energy production. Natural gas and crude oil share in this balance only in 10.5% and 9.7% respectively.

The balance of primary energy resources for electric energy production mentioned above is different for every state because it is given by certain, especially natural features of the state in question. A protection of its primary energy resources and thus also a hydroenergetic potential should be the basic strategic thesis of every state. Especially because this resource is ecologically the most tolerant energy resource, it does not threaten environment with pollution, possible ecological accidents and it also does not produce any wastes.

The term hydroenergetic potential will mean for the purposes of our next considerations "a primary technically usable hydroenergetic potential" (HEP in the following) of a state, a river basin or a river section.

HEP term will mean a sum of average yearly productions of built and realized hydroelectric power plants (VE) and small hydroelectric power plants (MVE) of the region.

HEP is calculated by a value 7,361 GWh/year at approximate installed capacity 2,575 MW in works of Výskumný ústav energetický Bratislava and VUPEK Bratislava [2], [3], [4]. If HEP is expressed in the amount of brown coal which would be required for production of the same amount of electric energy (so called coal equivalent), we get the amount of about 8.4 tons of this kind of fuel yearly including all of the negative aspects resulting from burning this amount of coal. About 2.3 mil tons of ash, 176 ktons of sulphur oxides, etc. for instance would be produced in a year.

Morphology and a central location in the continent of Europe is an important fact determining the size and distribution of HEP in the area of the Slovak Republic. These natural features of the Slovak Republic have predetermined that only one large European river - Danube, runs through the Slovak Republic. Even this one runs through the territory of the Slovak Republic only in the length of 22.5 km and in the length of about 149.5 km the Danube creates a border of the Slovak Republic with Austria and Hungary. Thus the section of the Danube to which the Slovak Republic is somehow entitled, which is however conditioned by agreements with the neighbors, has a length of about 172 km which represents about 6.6% of total usable length of the Danube.

Other Slovak rivers mostly only well in the Slovak Republic and run out from its territory. Thus the Slovak Republic can be called, exaggerating a little bit, as a roof of Europe. In order to be able to talk about water management in the Slovak Republic, a part of the water on this "roof" must be kept so that it could be available at the time of its lack. What is a role of water management and its accumulation reservoirs?

With respect to natural features of the Slovak Republic and the amount of electric energy consumed in the Slovak Republic, which was permanently decreasing after 1989 till 1993 (see tab.1) and since that year it has again had an increasing tendency, the HEP of the Slovak Republic cannot, even if it is utilized completely (7,361 GWh/year), cover electric energy consumption in the Slovak Republic. Thus building hydroelectric power plants in the Slovak Republic did not follow maximum production of electric energy by run of river VEs with a relatively small installed capacity, but since the very beginning of permanent utilization of HEP in the Slovak Republic, which can be dated since 1936 in which VE Ladce on the river Váh was put into operation, hydroelectric power plants which could carry out regulation services, i.e. operate in timely limited sections of increased electric energy consumption (peaks, at fast rise into peaks, coverage of emergency situations in the system, etc.) have been built as far as the circumstances allowed to do so.

This strict position of VEs in the electrification system of the Slovak Republic (also in the Czechoslovakia in the past) has also influenced design and a scheme of VEs, especially on our the most important river from the point of view of power engineering - the river Váh, on which every VE or a group of derivative VEs, starts with a weir or a reservoir, respectively the accumulation volume of which provides a regulation operation of VE. The first VE Ladce was built according to this scheme, too. D.Kočkovce weir has a useful volume of 2.0 mil. cubic meters, absorption capacity of turbines was 135 m^3/s originally, later it was changed to 150 m^3/s, whereas an average flow in a profile of D.Kočkovce weir is 133 m^3/s and it represents about 110 day water.

The difference between the maximum and minimum loads of the electrification system changes within several hours in an order of hundreds of MW. The course of the daily load of the electrification system of the Slovak Republic on September 24, 1996 including its coverage by the sources which are available in the electrification system of the Slovak Republic is shown in fig.1 as an example of load variations in the electrification system of the Slovak Republic and its coverage by individual sources.

The described position of VEs in the electrification system of the Slovak Republic is certainly reflected in statistics of energy resources in the Slovak Republic. The share of individual resources in coverage of a total electric energy consumption and the share of installed capacities of individual resources in the electrification system are shown in tab.1 and 2.

Distribution of HEP of the Slovak Republic to individual river basins is shown in fig.2. In this picture, it is obvious that the river Váh with 3,505 GWh/year is the most important river in the Slovak Republic and the Danube with 2,655 GWh/year (taking into account only the Slovak part) is the second one. The schedule of construction of individual VEs on the river Váh was affected especially by a power efficiency of the utilized section of the river Váh and technical and legislative problems which result in economic indicators of respective projects.

It results from the scheme of VEs on the river Váh, see fig.3, and the schedule of construction of VEs shown in tab.3, that the most appropriate sections of the "middle" Váh from the point of view of power engineering in which the river head is not still sufficient and the rate of flow is large enough and more over, the technical and legislative problems were not especially difficult, were utilized first of all. (The group Ladce - Ilava - Dubnica - Trenčín and Kostolná - N.Mesto - H.Streda). The sections with certain technical problems (e.g. slumps, flat reservoirs dammed on both sides, etc.) were also used later.

The system of hydro power projects Gabčíkovo - Nagymaros or only the hydro power project Gabčíkovo, respectively, which suffered from an excessive politicization of the problem, is a special case in utilization of HEP in the Slovak Republic.

Utilization of HEP in the Slovak Republic by the end of 1995, obvious in fig.2, reaches the value 3,918 GWh/year, i.e. about 53.2%.

From the European point of view it even is not the European average value in 1989 [5] which was 55.1%. As far as only the numbers are concerned, this balance does not sound alarming enough. However, if we realize that nearly a half of our HEP is not utilized which means that about 4.2 mil. tons of brown coal (for illustration, it should be mentioned that this is about 1.4 times the yearly production in the coal mines in Nováky in 1995) "flows", to put in metaphorically, out from the Slovak Republic territory. We think that these facts are worth thinking about for the top managers in this state to admit a true position in energy resources of the Slovak Republic to HEP, too and to raise the interest of a society above angry interests of departments and to implement clear and logical rules in HEP utilization.

Potential energy of water is directly converted into electric energy in utilization of a primary HEP. In case of a secondary hydroenergetic potential, it is a conversion of electric energy (especially at a time of its excess) into potential energy of water by its repumping from a lower reservoir into an upper one. At a time of lack of electric energy, electricity is produced in a turbine mode of operation and water gets into the lower reservoir. The cycle is closed and can be repeated. From this point of view, the pumped storage plants (PVE) in which this process takes place are not a source of energy but they act in the electrification system as accumulators - or electric energy regulators, respectively.

These projects consume energy for their operation (more energy is required for water accumulation than is gained in turbine mode of operation. Total efficiency of a repumping cycle is about 75% with the best PVEs. It results from the above that economy of PVE can be based only on a difference in the price of electric energy used for pumping of water - accumulation, and the price of produced electric energy or in a special appreciation of services which PVE offers to the electrification system.

Conditions for construction of PVE are certainly given by the characteristics of the site which must be appropriate not only from the point of view of morphology, geology, hydrology but also from the point of view of urbanistics, environment protection, etc. More over, mostly the large modern PVEs must be connected to corresponding sources of a primary energy, e.g. nuclear power plants, through corresponding transmission paths.

From the information mentioned above, it is obvious that PVEs are important from the point of view of operation of sources of energy in the electrification system not only as "sources" of energy at a time of lack but also as "consumers" of electric energy at a time of excess of the energy in the system. A regulation range of PVE is then given as a sum of absolute values of max. power input in pumped mode of operation and the power output accessible in a turbine mode of operation.

Four PVEs are connected to the electrification system in the Slovak Republic the basic parameters of which are shown in tab.4. The data is taken from [6]. Basic schemes of PVEs are described in the following [7]:

1. Dobšiná PVE uses water from the river Hnilec and transmits it into a basin of the river Slaná. Palcmanská Maša reservoir with 10.3 mil. cubic meters represents a supply reservoir filled with natural flows of the river Hnilec and also an upper reservoir for repumping the water from the reservoir in Vlčia dolina, 172 thous. cubic meters.
2. Ružin PVE is a hydroelectric power plant below a dam with a reservoir of a total volume 59.0 mil. cubic meters on the river Hornád. It is used for retaining of natural flows of the river and also as an upper reservoir of PVE. The lower reservoir of PVE is used for repumping and also for compensation of flows and has a volume of 3.7 mil. cubic meters - Ružín II.
3. L.Mara PVE is a dam hydroelectric power plant in which 4 power units are installed in total out of which two are reversible. The reservoir is used to compensate flow of the river Váh and also as an upper reservoir for repumping (reversible) units. The reservoir has a total volume of 360 mil. cubic meters. Bešeňová reservoir with a total volume of about 9.8 mil. cubic meters is a lower and also a compensation reservoir of this PVE.
4. Č.Váh PVE is the only PVE in the Slovak Republic without a natural water inflow into the upper reservoir so far. It is also our largest PVE in which 6 power units are installed. The lower reservoir retains water from the river Čierny Váh and it is also used for "storage" of water in a turbine mode of operation. The upper reservoir is an artificial one without a natural inflow. Both are connected with three armored supply conduits. Available volume of upper and lower reservoirs is 3.7 mil. cubic meters, whereas the total volume of the lower reservoir is 4.7 mil. cubic meters.

Referring to the requirements placed onto our electrification system in relation to connection to UCPTE, especially to the requirement of a fast coverage of an emergency reserve of the system, a way of utilization of the PVE was also changed. This reserve is kept in the most convenient way in PVEs which results in blocking of a part of the volume of upper reservoirs of PVEs and also reduction in production from repumping. This fact is also reflected in the statistics of electric energy production shown in tab.1.

HEP utilization, both primary and secondary ones, is carried out in the conditions of the Slovak Republic in multipurpose water projects with energetic utilization as a rule. It means that energetic utilization is only one of the benefits of these projects. However, it should be mentioned immediately that in the present economic conditions, the energetic utilization is the main and in most of the cases the only one benefit of these multipurpose hydro power projects which can be paid for. HEP is not responsible for this economic faux pas but the incomplete economic relations of our legislation are.

The absurdity of economic relations in HEP utilization described above then finally leads to discrimination of HEP utilization and there is an effort to hang everything which the multipurpose hydro projects contain on it. Only this way it can happen that in conditions of the Slovak Republic an ecological efficiency of HEP utilization is discussed even if it does not produce any wastes thus it does not require any permanent ash dumps or storages for nuclear waste.

The facts that due to a long term operation of multipurpose hydro projects no negative impact on environment was proved are also neglected and vice versa recreation zones (Orava, L.Mara, Pacmonská Maša. etc.) and even protection zones or areas (Tr.Biskupice weir, Drahovce weir, etc.) were created in the whole range of these projects. These facts can only hardly be found in other energy sources.

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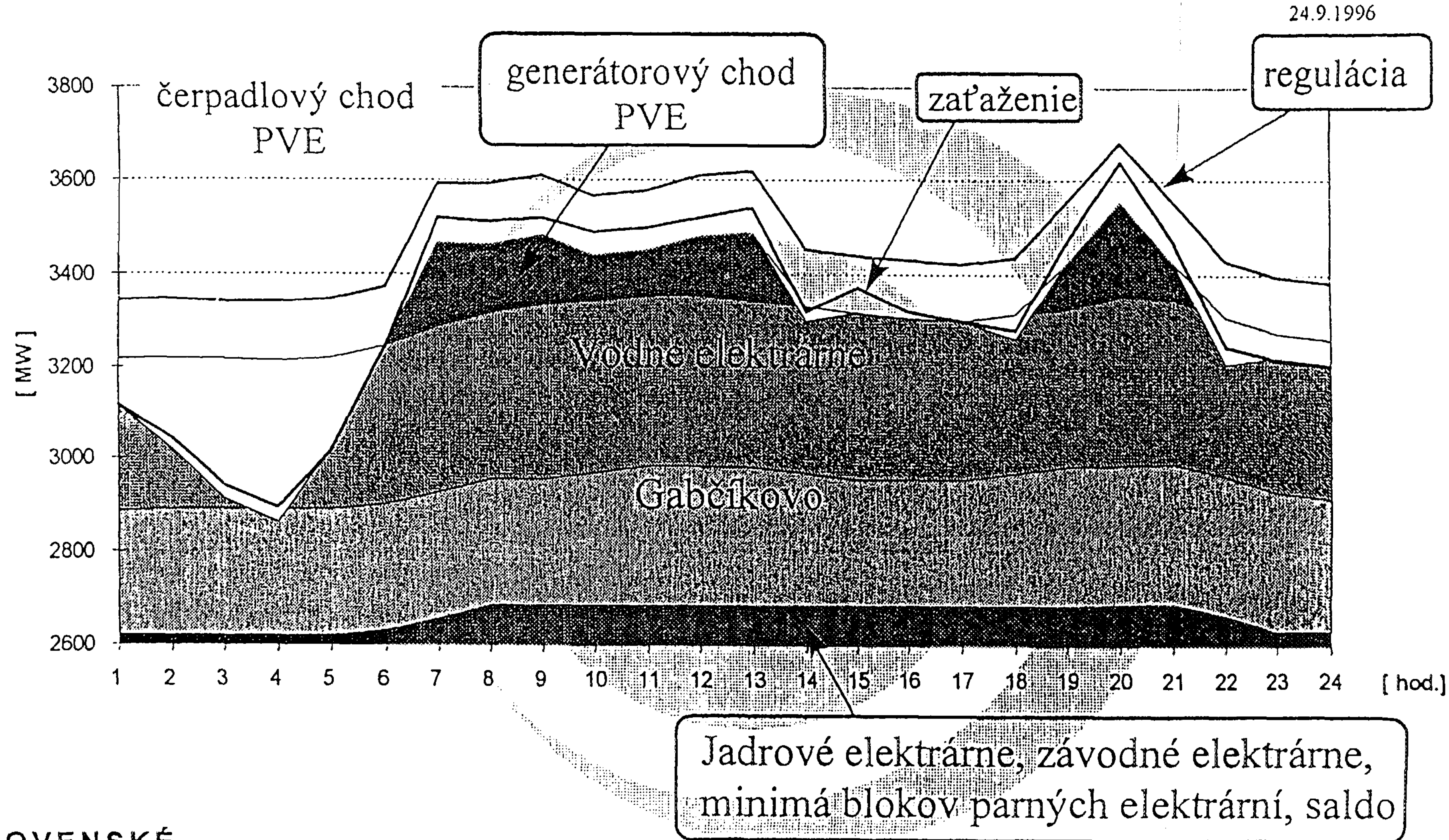
Fig. 1. Participation of water power stations on daily diagram loading of energetic system SR

Plán pokrývania zaťaženia zdrojmi



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Obr. č.2

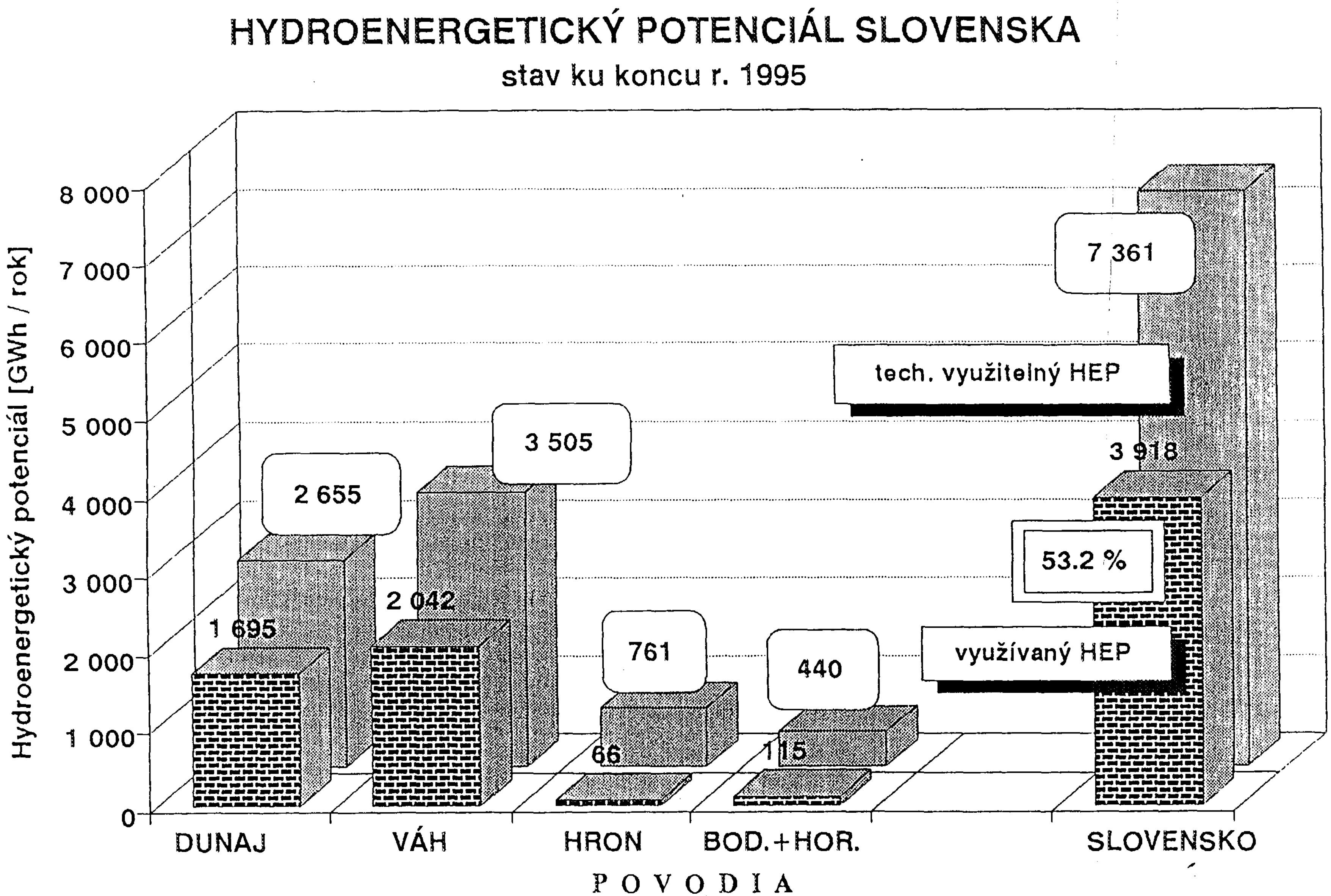
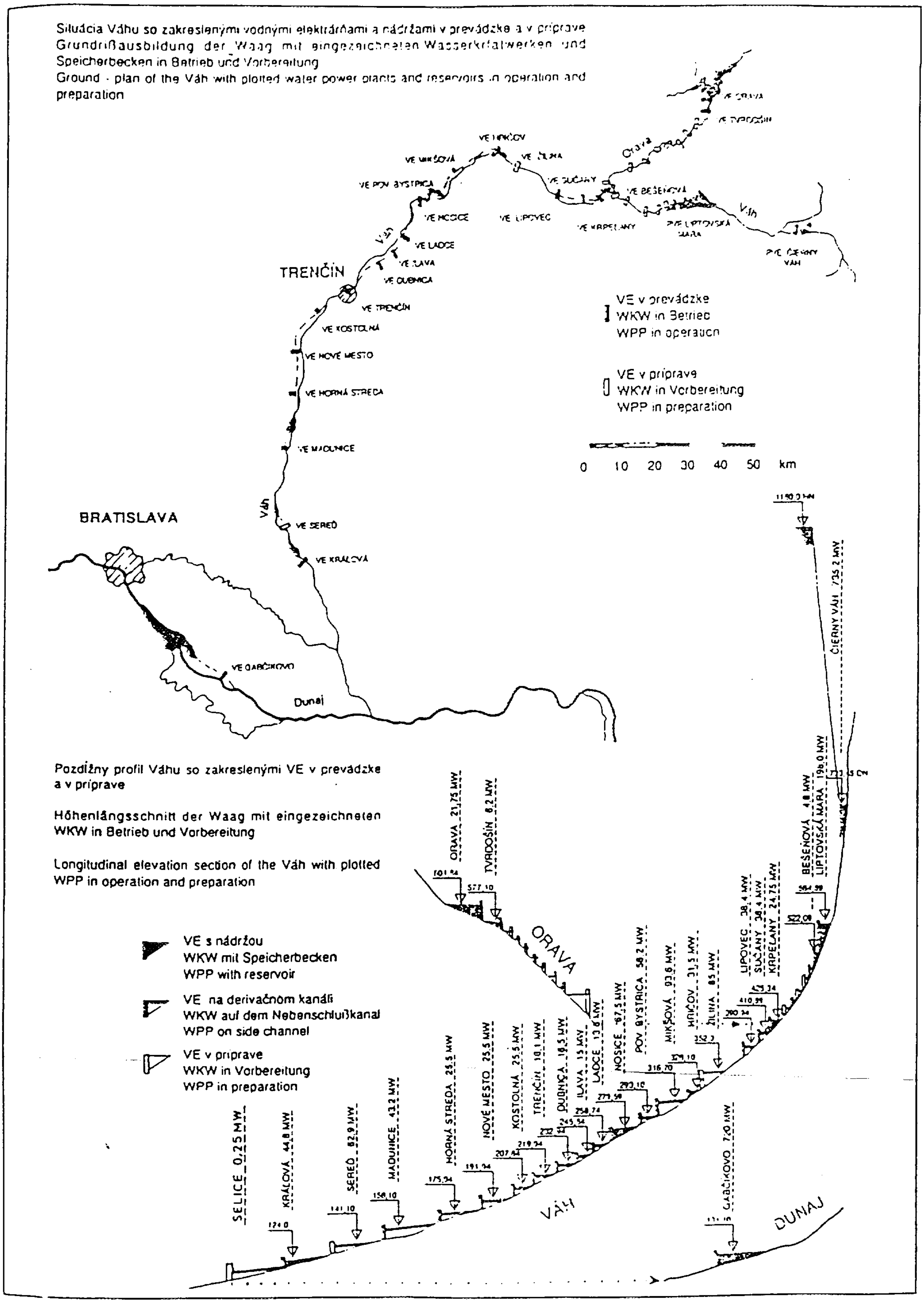


Fig. 2. Hydroenergetic potential of Slovakia

Obr.č. 3



Situácia Váhu so zakreslenými vodnými elektrárňami a nádržami v prevádzke a v príprave
Grundrißausbildung der Waag mit eingezeichneten Wasserkraftwerken und Speicherbecken in Betrieb und Vorbereitung
Ground - plan of the Váh with plotted water power plants and reservoirs in operation and preparation
TRENČÍN
BRATISLAVA
Váh
Orava
Dunaj
VE ORAVA
VE TVRDOŠÍN
VE HRIČOV
VE MIKŠOVÁ
VE ŽILINA
VE POV. BYSTRICA
VE SUČANY
VE BEŠEŇOVÁ
VE NOSICE
VE LIPOVEC
VE KRPEĽANY
PVE LIPTOVSKÁ MARA
PVE ČIERNY VÁH
VE LADCE
VE ILAVA
VE DUBNICA
VE TRENČÍN
VE KOSTOLNÁ
VE NOVÉ MESTO
VE HORNÁ STREDA
VE MADUNICE
VE SEREĎ
VE KRÁĽOVÁ
VE GABČÍKOVO
VE v prevádzke
WKW in Betrieb
WPP in operation
VE v príprave
WKW in Vorbereitung
WPP in preparation
0 10 20 30 40 50 km
Pozdĺžny profil Váhu so zakreslenými VE v prevádzke a v príprave
Höhenlängsschnitt der Waag mit eingezeichneten WKW in Betrieb und Vorbereitung
Longitudinal elevation section of the Váh with plotted WPP in operation and preparation
VE s nádržou
WKW mit Speicherbecken
WPP with reservoir
VE na derivačnom kanáli
WKW auf dem Nebenschlußkanal
WPP on side channel
VE v príprave
WKW in Vorbereitung
WPP in preparation
ČIERNY VÁH 735,2 MW
BEŠEŇOVÁ 4,8 MW
LIPTOVSKÁ MARA 198,0 MW
ORAVA 21,75 MW
TVRDOŠÍN 6,2 MW
LIPOVEC 38,4 MW
SUČANY 38,4 MW
KRPEĽANY 24,75 MW
NOSICE 67,5 MW
POV. BYSTRICA 58,2 MW
MIKŠOVÁ 93,6 MW
HRIČOV 31,5 MW
ŽILINA 85 MW
HORNÁ STREDA 25,5 MW
NOVÉ MESTO 25,5 MW
KOSTOLNÁ 25,5 MW
TRENČÍN 10,1 MW
DUBNICA 16,5 MW
ILAVA 15 MW
LADCE 18,6 MW
SELICE 0,25 MW
KRÁĽOVÁ 44,8 MW
SEREĎ 82,9 MW
MADUNICE 43,2 MW
GABČÍKOVO 720 MW
ORAVA
VÁH
DUNAJ

Výroba s spotreba elektrickej energie v SR v GWh

Tabuľka č. 1

Rok	Výroba podľa druhov elektrární						Saldo	Spotreba	Podiel výroby na spotrebe v %						
	parné	jadrové	vodné	prečerp.	závodné	spolu	Imp.-exp.		parné	jadrové	vodné	prečerp.	závodné	spolu	dovoz
1970	6239	0	1904	17	1995	10155	3664	13819	45.1	0.0	13.8	0.1	14.4	73.5	26.5
1975	8449	187	1838	122	2773	13369	5872	19241	43.9	1.0	9.6	0.6	14.4	69.5	30.5
1980	10585	4523	2208	109	2651	20076	3347	23423	45.2	19.3	9.4	0.5	11.3	85.7	14.3
1985	7547	9382	2158	484	2936	22507	4216	26722	28.2	35.1	8.1	1.8	11.0	84.2	15.8
1989	6573	12157	2005	592	2739	24066	5432	29498	22.3	41.2	6.8	2.0	9.3	81.6	18.4
1990	6893	12035	1902	581	2657	24068	5229	29297	23.5	41.1	6.5	2.0	9.1	82.2	17.8
1991	6609	11689	1461	402	2571	22732	4340	27072	24.4	43.2	5.4	1.5	9.5	84.0	16.0
1992	6556	11049	1937	395	2409	22346	3470	25816	25.4	42.8	7.5	1.5	9.3	86.6	13.4
1993	6258	11022	3460	397	2280	23417	1112	24529	25.5	44.9	14.1	1.6	9.3	95.5	4.5
1994	5688	12135	4300	254	2363	24740	422	25162	22.6	48.2	17.1	1.0	9.4	98.3	1.7
1995	6813	11437	4908	264	2483	25905	1419	27324	24.9	41.9	18.0	1.0	9.1	94.8	5.2

Table 1. Production and consumption of elektrical energy in SR (GWh)

Inštalovaný výkon elektrární v ES SR

Tabuľka č. 2

Rok	Inštalovaný výkon v MW				Podiel typov elektrární v %		
	PE	JE	VE	Spolu	PE	JE	VE
1980	2831.2	860.0	981.7	4672.9	60.6	18.4	21.0
1981	2826.2	860.0	1316.5	5002.7	56.5	17.2	26.3
1982	2932.2	860.0	1539.5	5331.7	55.0	16.1	28.9
1983	2948.7	860.0	1539.5	5348.2	55.1	16.1	28.8
1984	2996.0	1320.0	1540.2	5856.2	51.2	22.5	26.3
1985	3013.0	1760.0	1585.0	6358.0	47.4	27.7	24.9
1986	3019.0	1760.0	1585.0	6364.0	47.4	27.7	24.9
1987	3018.0	1760.0	1584.1	6362.1	47.4	27.7	24.9
1988	2986.0	1760.0	1654.0	6400.0	46.7	27.5	25.8
1989	2970.0	1760.0	1654.5	6384.5	46.5	27.6	25.9
1990	2940.0	1760.0	1652.1	6352.1	46.3	27.7	26.0
1991	2901.5	1760.0	1652.1	6313.6	46.0	27.9	26.2
1992	2901.5	1760.0	1832.1	6493.6	44.7	27.1	28.2
1993	2959.2	1760.0	2106.0	6825.2	43.4	25.8	30.9
1994	2965.2	1760.0	2205.3	6930.5	42.8	25.4	31.8
1995	2969.7	1760.0	2386.8	7116.5	41.7	24.7	33.5

Table 2. Installed power plants output of energic system in Slovakia

Tabuľka 3

Výroba elektrickej energie jednotlivých VE od ich uvedenia do prevádzky do konca r. 1995 (kWh)					
Názov VE	uved. do prev. (rok)	celková doterajšia výroba (W)	názov VE	uved. do prev. (rok)	celková doterajšia výroba (W)
Orava	1953	1 192 230 386	Nosice	1957	5 978 157 733
Tvrdošín	1979	199 459 900	Ladce	1936	4 500 825 613
Čierny Váh	1981	5 212 070 211	Ilava	1946	3 908 411 563
Lip. Mara	1975	2 548 426 800	Dubnica n./V	1949	3 935 172 839
Bešeňová	1976	330 414 300	Trenčín	1956	3 384 821 402
Krpeľany	1957	2 265 261 404	Kostolná	1953	4 778 567 700
Sučany	1958	3 473 503 970	Nové Mesto	1953	4 805 264 901
Lipovec	1960	2 971 077 300	Horná Streda	1954	4 924 772 367
Hričov	1962	1 923 827 800	Madunice	1960	5 046 775 700
Mikšová I	1963	5 724 955 600	Kráľová	1985	1 056 375 700
Mišová II	1971–1984	13 041 480			
P. Bystrica	1963	3 519 029 800	spolu		71 692 480 469

Table 3.

Electricity production of individual VES since putting them into opperation till - the end of 1995 (kWh)

Tab. č. 4

Prehľad základných parametrov PVE na Slovensku

Názov PVE	Uvedenie do prevádzky	Typ turbín - čerpadiel	Celkový dosaž. výkon PVE v turbín. prevádzke	Celkový výkon PVE v čerpadlov. prevádzke	Regulačný rozsah PVE
	rok		MW	MW	MW
Dobšiná	1956	2xFrancis 2xodstred. čerpadlo	22,8	18	40,82
Ružín I.	1968	2xFrancis. - reverz.	60	66	126
Lipt. Mara	1975	2xdiagonálna- reverz. 2xKaplan	198	106	304
Č. Váh	1981	6xFrancis 6xdvojtupňové jednonátokové čerp.	660,75	664,2	1324,95

Table 4.

List of basic parametres of PVEs in the Slovak Republic

Tab.: 4...............

List of basic parameters of PVEs in the Slovak Republic

názov PVE - PVE name

uvedenie do prevádzky - putting into operation

typ turbín-čerpadiel - type of turbines-pumps

celkový dosažiteľný výkon PVE v turbínovej prevádzke - total available capacity of PVE in a turbine mode of operation

celkový výkon PVE v čerpadlovel prevádzke - total power output of PVE in a pumped mode of operation

regulačný rozsah PVE - regulation range of PVE

Economic Problems of Utilization of Hydroenergetic Potential of the Slovak Republic and Possibilities for their Solution

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This paper, with respect to its extent, cannot be an exhausting economic analysis of utilization of hydrenergetic potential in the Slovak Republic. Its aim is to clarify basic inputs into economic calculations of hydro power projects which then can drastically affect efficiency of these projects in different ways as there are no distinct economic and legal regulations in our country as the hydroenergetic potential (HEP) utilization is concerned.

We think that distorted inputs trapped with different ideas of groups sharing in HEP utilization can not provide, in a final phase, objective evaluation of HEP as one of the resources of electrification system (ES) of the Slovak Republic especially because each of these groups first of all pushes its own interests through. Consequently any methodology for evaluation of ES resources, however precise it may be, can then be used. Inputs which are not objective cannot be used for an objective evaluation of respective resources. In our case, for an objective evaluation of HEP utilization.

Evaluation of economic parameters of individual resources of ES and their economic profitability should finally reflect in a composition of resources. Fundamentally it is also valid for the Slovak Republic which has inherited the composition of resources from the past. In 1995, the share of individual resources of ES in production in the Slovak Republic was as follows:

- nuclear power plants - 41.86%
- steam power plants - 24.93%
- hydroelectric power plants - 18.93%
- factory power plants - 9.09%
- import - 5.19%

However, in the same year, the individual resources of ES in the Slovak Republic shared in a balance of installed capacity - 7,114 MW according to [1] as follows:

- nuclear power plants - 24.7%
- steam power plants - 31.0%
- hydroelectric power plants - 33.4%
- factory power plants - 10.9%

It is obvious from the facts mentioned above that each of the basic sources of ES has its place in this balance. That e.g. capacity of nuclear power plants is the most utilized from the point of view of time thus their basic role is to cover the basic part of a daily diagram of load. Compared to this, hydroelectric power plants with their largest share in installed capacity are less utilized from the point of view of time and are designed to cover half peak or peak loads, respectively. Thus it would be a rather unlucky step if one of the resources were preferred and another one shifted into a background although with a reasoning that it has to wait some time. Unfortunately, these directions appear in a perspective planning and are also reasoned by unfavorable economic indicators of new hydro power projects. Whereas the fact that the costs for production of 1 MWh of electric energy are in VE (hydroelectric power plant) the lowest of all resources is circumvented.

In HEP utilization, especially of a primary hydroenergetic potential, mostly construction and operation of multipurpose hydro power projects with power utilization are of concern in the Slovak conditions. This fact results then in a different approach to formulation of inputs for an economic evaluation of these multipurpose projects as resources for ES of the Slovak Republic. Namely, hydro power projects are of concern and they have several benefits and electric energy production is only one of them. In the past, this problem used to be solved by cooperation between two departments - power engineering and water management ones, (the Ministry of National Economy and the Ministry of Agriculture at present) so that the power engineering department financed a technological part of VE from the funds of the power engineering department or loans taken over by the power engineering department or some of its organizational units, respectively.

Then the water management department financed the remaining water management part of the hydro power project from a national budget, whereas the funds for financing the building part of VE or respective parts of the hydro power project serving exclusively to power engineering, respectively received the Slovak national budget, which was funded from a federal one, from a power engineering category of budget. Then power engineering department, after finishing the construction, received from the water management department the objects serving exclusively for power engineering in a form of gratis transfer and for the remaining parts of the objects serving also for other purposes, it paid yearly so called "rent" from hydro power projects to water management operator of the hydro power plant. Nearly the same scheme was also used in construction of SVD G-N till the end of 1992.

Fundamentally, the largest PVE in our country - PVE Čierny Váh, was also financed according to this scheme. As all of the objects in this construction serve exclusively for power engineering purposes and they do not have water management effect, the costs for this PVE were covered exclusively by the power engineering department.

Since 1993 the national budget of the Slovak Republic has not contained a budget category for construction of development structures of water management (neither SVD G-N but also neither hydro power project Žilina). That is the reason why different proposals for financing the water management development investments or water management parts of hydro power projects, respectively have been occurring.

Unfortunately, all of the proposals had to be based on a controlled price of the only product of hydro power projects, i.e. electric energy, which can be paid for. This is the only source which can be used to cover redemption of loans taken over for construction of activities of water management in conditions in which a state as a tax collector does not participate in financement of parts of hydro power projects beneficial to the public. In this situation, it is nearly the same if, within one hydro power project, the objects which are related to utilization of hydro power only as a matter of peripheral importance or they are not related at all, are covered in this way or so called "solidarity" financement is of concern in which the profits from electric energy production in one hydro power project with a power utilization are also "transferred" into a construction of parts of other new hydro power projects beneficial to the public.

Anyway, these objectives are with their consequences directed against further utilization of HEP as they rapidly decrease economic indicators of hydro power projects up to such extent that these are becoming to be of no interest as prospective sources of ES in the Slovak Republic.

Otherwise, this kind of economic unbearable load of multipurpose hydro power projects with a power utilization meets the conditions not to stop construction of water management projects at present. However there is one open question of redemption of loans taken over for these structures. The situation is getting even more complicated by the fact that at present a state, or a region which is affected by the hydro power project and will also use its functions beneficial to the public, does not have any effort or possibility to participate in a financement of the construction of parts of hydro power projects beneficial to the public or take over any obligations for future, e.g. a warranty of tax vacation for a business entity financing the construction of a complex multipurpose hydro power project, etc. In this way, the funds collected from HEP utilization are not returned back into a sphere of further development of HEP utilization, but into other spheres which should be financed from other resources and not from the electricity production. It is obvious that a state, as an owner of HEP, has this right to redistribute funds collected by HEP utilization but at the same time the state should be aware of the fact that this way it makes one of its largest primary energetic resources unfavorable and the state itself exercises pressure for increasing the price of electricity.

Similar redistribution of funds from electric energy production in the existing VEs into a construction of other power resources also does not support HEP utilization. It is obvious that the reasoning for "economic unfavourability" to construct hydro power projects (HEDs) in conditions in which a business entity having an effort to use HEP must finance a complete hydro power project finally represents less effort than to clean the financement of HEP utilization from different burdens of financement of everything which is otherwise related to the hydro power project but is not related to electric energy production.

If the conditions of HEP utilization in a developed part of the world or Europe were the same as those that are in our country at present, the level of HEP utilization would not be 70-80 and more percent. A level of HEP utilization 53.2% by 1995 was basically reached in conditions of financement of HEDs in the way described by the end of 1992.

Another fact of an economic evaluation of resources of our ES which discriminates HEP utilization is the fact that the Slovak power dispatching centre cannot imagine otherwise safe operation of our ES without a power reserve which is installed in VEs and especially in PVEs but its valuation is done at present only through a kWh produced, which is certainly an economic nonsense, because capacities installed in VEs and PVEs have been prepared since their design for a low time utilization with a relative high power output which represents high investment costs. In evaluations these power outputs are compared with a time utilization of other resources which sometimes reach up to 100%. It also seems that a comparison of utilization of a domestic power source, as HEP is, which is in case if it is not used irrevocably depreciated and literally "flows" out form the area of the Slovak Republic, e.g. with a steam-gas cycle based on an imported natural gas is not the luckiest measure because risks of gas import cannot be compared to the risks of a probability of occurance of hydrologic events anyway.

A general problem in construction of development investments and thus also the investments in the area of HEP utilization is lack of a free capital available at acceptable interest rates. In a situation of complete development investments financement at e.g. 17% interest rate, the investments become more expensive compared to original budget calculations by up to 50%. For the investors of development constructions, e.g. also hydro power projects, it means that they are evaluated according to the same bank rules in the case of financement than the investors in a consumer industry although a strategic utilization of domestic primary power resources is of concern.

Deallocation of prices of inputs into electric energy production whether in the areas of prices of fuels, raw materials, supplies, work, etc. and keeping so called controlled price of an output product, i.e. electric energy, a disproportion occurs which will sooner or later exhaust all reserves with a monopoly electric energy manufacturer, i.e. SE a.s. in our country. Finally, neither this manufacturer will be able to meet its fundamental function - a fault-free supply of the Slovak national economy and inhabitants with electric energy. None enterprise based on a market principle can pay long time without any limits for imported power to cover a balance in our ES, which e.g. in 1995 reached about 5.2% of total electric energy consumption, more than it can get for it in a domestic market.

If we realize that private businesses can also act in the area of HEP utilization, the deallocation of inputs and keeping the controlled price for electricity together with excessive interest rates are the main reasons why entrepreneurship in the area of HEP utilization has not reached any extensive development so far and if we add sometimes excessively severe requirements of environment protection institutions, the entrepreneurship in this area remains very risky.

The possible ways towards an increase in HEP utilization can be discussed at present only on a level of theoretical thoughts because in the same way as it used to be in the past, when several "governmental regulations" on utilization or an increase in utilization of HEP were issued, all of them remained only on the level of wishes of their authors because they did not deal with conditions for increase in utilization of hydroenergetic potential. However, the present concept of "Power concept of the Slovak Republic by 2005" expects some increase in HEP utilization but it also does not deal, neither in a hint, with sources of financement and even basic legal rules and legislation in general concerning protection and utilization of HEP. Without these basic assumptions there is a threat that also the present "Power concept of the Slovak Republic" in the area of increasing utilization of HEP will remain on a level of preceding governmental regulations.

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SK97K0333

Modernization of Control Systems of Primary and Secondary Hydroenergetic Sources of Electricity from the Point of View of their Fulfillment of Important Functions in Operation of a Power Engineering System in the Slovak Republic

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A. Introduction

Shortly after putting the first more important hydroelectric power plant in the Slovak Republic into operation in 1936 (VE Ladce) and subsequent construction of other VEs on this river, requirements for these sources of electricity have increased not only for the amount of electricity produced but also the use of some specificities, which can be offered by these sources (peak loads coverage, load coverage in replacement of faulty sources, participation in ES frequency control, participation in ES voltage control, etc.) in operation of a power engineering system (ES), has started. Finally, requirements for electricity, produced from primary energetic sources (hydroelectric power plants - VE) not only as for the amount but also for fulfillment of qualitative functions in operation of ES SR resulted in a faster construction of new VEs but an emphasis on qualitative functions of VEs has also supported development and construction of pumped storage plants (PVE) whereas the fulfillment of qualitative functions by hydroelectric power plants and PVEs in operation of ES has also required introduction of automatic systems on a level of actual hydroalternators (turbine - generator), their automatic starting, controlling their operation and shutting down an automatic control system of VE and PVE as a single unit with an optimum selection of a number of operational units, distribution of active and reactive loads, etc., automatic system of optimal control of cascades of hydroelectric power plants built on one and more rivers with both tough and looser hydraulic relationships and also an automatic control system of a group of VEs on one river from the point of view of optimum operation of two independent international ESs. Construction and introduction of these automatic systems has started from the second half of 50s (1956) and they were on a level of knowledge and technical means available at that time (from 1956 until now). Solution of problems of these automatic systems related to operation of VEs, PVEs and complete control system of VE and PVE is shown e.g. in [6], [7], [8].

Many of these solutions have been upgraded, these upgrades were mostly represented by advanced automatic elements in a range from an automatic element, represented by a relay, up to a microcomputer element.

However, at present, I expect that in upgrading and construction of new VEs and PVEs it is time to pay attention, from the point of view of a design of control systems of all levels, first of all to the actual system which we want to be automatically controlled. Thus it is necessary to pay attention to an actual description of a system weather for instance its mathematical description sufficiently corresponds to a behavior of the system in real operation, weather in the past, with an insufficient quality and price availability of technical means it was not required to describe some functions of the controlled system in a very simplified form, e.g. weather linearity of processes was not accepted in cases in which the processes were with a rough non-linearity, etc. New requirements for theoretical reevaluation of models of ES elements can also require new knowledge in the area of operation of growing electrification systems covering several international ESs.

Referring to the ideas on upgrading of control systems of VE and PVE mentioned above, I want to discuss an automated control system of a hydroelectric generating set (turbine - generator) in the following.

B. Automatic Control System of a Hydroelectric Generating Set

An automatic control system of a hydroelectric generating set covers a control of all of the modes of operation of a hydroelectric generating set - a turbine, a generator and their accessories - so that the required criteria for quality of control were met while keeping stability of control processes.

A hydroelectric generating set control is a fundamental section of this control system.

Modernization of the existing hydroelectric generating sets and their accessories, design and construction of new hydroelectric generating sets, new theoretical knowledge on production equipment of VEs and PVEs, new knowledge in the area of theory of control, modern technical means for automated control systems and new requirements for fulfillment of production functions of hydroelectric generating sets in complicated ESs require to use the knowledge and requirements mentioned above also in modernization of the existing and construction of new control systems of hydroelectric generating sets to a maximum extent.

First of all, the following is required to meet this goal:

- to reevaluate a mathematical description of water turbines and generators from the point of view of control of their operational processes
- to reevaluate main control circuits of a hydroelectric generating set from the point of view of fulfillment of production functions of both present and future periods
- to reevaluate an affect of non-linearities, occurring in control circuits of a hydroelectric generating set, which have been replaced with linear relationships so far
- to reevaluate possibilities of a stability evaluation of control circuits of a hydroelectric generating set using exact methods, simulation means or their combination, respectively.

1. Description of a Hydraulic Circuit and a Water Turbine from the Point of View of a Main Control Circuit - Speed Control

A water turbine operation is strongly affected by its hydraulic circuit and a generator. It is a very complicated non-linear system requiring to do some simplification from the point of view of a speed control.

Head (H), flow (Q), a control element position (Y) and a second control element position (Y_O), if applicable, will be considered as input variables to this system.

Turbine speed (n), (velocity (Ω)) and moment of force (M_T) which give a turbine power output (P_T) will be of our interest as output variables.

In a normal operation, a hydroelectric generating set is operating into a large capacity ES, speed (ES frequency) is changed slightly whereas both power output and moment can be changed in a full control range. So, turbine power output depends on a position of a turbine flow control element. The relationship of a control element and a turbine power output is non-linear as a rule and depends on a turbine type, too.

With respect to simplification, we will not differentiate turbines from different points of view and we will not discuss different turbine designs either, however, we will consider their classification into two groups, equal-pressure and over-pressure ones.

1.1. Equal-Pressure Turbine Static Characteristics

Water pressure at both the turbine wheel input and output of an equal-pressure turbine (e.g. Pelton turbine) is the same thus water flow through a turbine does not depend on a turbine speed and a total pressure energy of water given by a water head is changed in a control element into a kinetic energy, i.e. water speed, a theoretical value of which is as follows:

$$v = (2gH)^{0,5} \qquad (1)$$

whereas its actual value v_s is reduced, compared to the theoretical value, by the loss in a control element.

Water flow through an equal-pressure turbine depends only on an effective opening of a control system.

$$Q = f(Y) \qquad (2)$$

Equal-pressure turbine moment is given by:

$$M = kQ(v_s - v_0) \quad (3)$$

k ... turbine constant; Q ... flow through a turbine; v_s ... velocity of water flowing out of a control element; v_0 ... circumferential velocity of a turbine.

It results from the equation (3) that, at a constant turbine speed, an equal-pressure turbine moment is proportional to the water flow through a turbine, whereas, at a constant flow at the given head, the moment is the largest one if a circumferential speed of a turbine $v_0 = 0$.

$$M_{max} = k.Q.v_s \quad (4)$$

The following can be derived for the value of a proposed moment for the given power output P_{max}, nominal water flow through a turbine Q_n and the given head:

$$M_n = k.Q_n.v_s/2 \quad (5)$$

The following equation can be obtained by dividing equations (3) and (5):

$$\frac{M}{M_n} = \frac{Q}{Q_n} \cdot \frac{v_s - v_0}{v_s/2}$$

$$m = q\ (2 - v_0^*);\ v_0^* = v_0/(v_s/2) \quad (6)$$

m ... a relative moment; q ... a relative flow; v_0^* ... a relative circumferential velocity.

With relative variables, v_0^* can be replaced with a relative speed n^*, and then we can obtain the following:

$$m = q\ (2-n^*) \quad (7)$$

As a relative flow depends on a relative opening of a turbine control element, the following can be written for the moment:

$$m = f(y)\ (2-n^*). \quad (8)$$

1.2. Over-Pressure Turbine Static Characteristics

A turbine wheel with over-pressure turbines (Kaplan, Francis, ...) operates at an overpressure, whereas only a part of a water head is consumed for creation of a kinetic energy being output from the distribution mechanism, the other part is changed into a kinetic energy in a turbine wheel (when neglecting the part of energy consumed to overcome a centrifugal force, surge loss, ...). Thus the expressions shown for equal-pressure turbines can be used for over-pressure turbines only with some limitations.

Flow in over-pressure turbines depends on two variables and it is not easy to determine the relationships. Thus it seems to be convenient to measure a set of curves $q = f\ (y,n^*)$ on a model turbine wheel and save it into a turbine model memory. A point of intersection of all lines $q = f(y)$ can be determined by approximation from the measured curves and equations for a set of curves can be written for respective n^*.

$$q = k_1(y-y_c)+q_c;\ k_1=f(n^*);\ A(y_c,q_c). \quad (9)$$

A (y_c, q_c) ... point of intersection coordinates.

The moment is proportional to flow, however a value of the moment changes with speed. In a similar way as it was done with the flow lines, a set of moment lines can be led into a common point of intersection B (q_B, m_B). A general equation for the moment determination is as follows:

$$m = k_2(q - q_B) + m_B; \; k_2 = f(n^*) \tag{10}$$

1.3. Equal-Pressure Turbine Dynamic Characteristics

As for its dynamic aspect, the flow q of an equal-pressure turbine at its changes due to changes in an opening of a turbine control mechanism is affected by a water mass in a penstock. Certain time (T_w) is required to set the water in the piping to motion.

$$T_w = \frac{v_w}{a};$$

T_w... time constant "water rise"
v_w... water velocity in a piping with a cross section S; (11)
a ... water acceleration

The energy required for acceleration of the water in the piping is covered from the head. The following can be derived for a specific change in flow.

$$q = \frac{Q}{Q_{max}} = y - y_A \cdot 0,5 \; T_w \frac{d_q}{dt} \tag{12}$$

or after carrying out Laplace transformation respectively, the following can be written:

$$q(s) = \frac{1}{1+0,5 y_A T_w s} \cdot y(s) \tag{13}$$

whereas, the transfer function q(s)/y(s) is given as follows:

$$\frac{q(s)}{y(s)} = \frac{1}{1+0,5 y_A T_w s} \tag{14}$$

y_A... a specific opening of a distribution mechanism in the investigated area ($y_A = Q/Q_{max}$).
The equations (13), (14) show a delayed relationship of a water flow on a change in the opening of a distribution mechanism, a time constant of which depends on a specific opening y_A and the time of water rise T_w.

As, during a change in the opening of a turbine distribution mechanism, a change in a water flow occurs only after some time, it is obvious that in a transient process, a water outlet velocity from the turbine distribution mechanism v_w must also change and thus a moment of the turbine must also change in a transient process.

The following can be proved for a specific outlet velocity:

$$v^*(s) = 1 - \frac{0,5 \; T_w s}{1+0,5 y_A T_w \cdot s} \, y(s) \tag{15}$$

Taking into account the equations (13) a (15) for a specific value of a turbine moment in a transient process, the following can be written:

$$\frac{m(s)}{y(s)} = \frac{2-n^* - y_A T_w s}{1+0{,}5 y_A T_w s} \tag{16}$$

A change in a turbine speed does not occur immediately if a turbine moment is changed, which is prevented by an influence of mass of rotating parts, whereas the following applies:

$$\frac{n^*(s)}{m(s)} = \frac{1}{T_a s} \tag{17}$$

T_a... time constant of the set (start time of the set)

The equation (17) represents a transfer with an integration action. However, with the real systems, this transfer is usually proportional to a first order delay which is usually caused by a self-regulating capability of the set e_{str} and a self-regulating capability of ES (e_{ES}). Then, for a summary coefficient of self-regulation $e_c = e_{str.} + e_{ES}$ the following can be written instead of the equation (17):

$$\frac{n^*(s)}{m\ (s)} = \frac{1}{T_a s + e_c} \tag{18}$$

For a speed change at an opening change of the control mechanism of equal-pressure turbines, the following can be derived:

$$\frac{m(s)}{y(s)} = \frac{2-n^* - 0{,}5\ T_w y_A 2s}{1 + 0{,}5 y_A T_w s} = \frac{1 - y_A T_w s}{1 + 0{,}5 T_w y_A s} \qquad (n^*=1)$$

The following can be set when taking the equation (17) into account:

$$\frac{n^*(s)}{y(s)} = \frac{1 - y_A T_w s}{s\ T_a(1 + 0{,}5\ T_w y_A s)} = \frac{1 - y_A T_w s}{0{,}5\ T_w y_A T_a s^2 + T_a s} \tag{19}$$

When taking the equation (18) into account:

$$\frac{n^*(s)}{y(s)} = \frac{1 - y_A T_w s}{0{,}5\ y_A T_w T_a s^2 + (T_a + 0{,}5\ y_A e_c T_w)s + e_c} \tag{20}$$

1.4. Over-Pressure Turbine Dynamic Characteristics

A water head change into a kinetic energy or velocity v_{w1}, respectively in a turbine distribution mechanism and an increase in a specific velocity of the water in a turbine wheel with an over-pressure turbine is done according to the following equation:

$$H' = \frac{v_{w1}^2}{2g} + \frac{v_{02}^2 - v_{01}^2}{2g} = kQ^2 + \omega^2\ (R_2^2 - R_1^2) \tag{21}$$

v_{w1}... water velocity at an intake into a turbine wheel

v_{01}, v_{02}... relative velocity of water at the beginning or end of a turbine wheel channel, respectively

R_1, R_2... a turbine wheel radius at the intake or outlet from a turbine wheel, respectively

ω... turbine angular velocity
k... constant

The following can be stated for small changes of specific variables, taking the equation (21) into account:

$$\frac{H}{H_{max}} = \alpha \frac{Q^2}{Q_n^2} + (1-\alpha) \frac{n^2}{n_n^2} \tag{22}$$

If a specific small change in a head acts on a specific change in a flow and a specific change in speed, the following can be obtained after derivation of the equation (22):

$$h = \frac{d}{dt} (\alpha(q - q_y)^2 + (1 - \alpha)n^{*2}) \tag{23}$$

If we apply a general expression for a hydraulic impedance for the piping:

$$\frac{h(s)}{q(s)} = z(s) \tag{24}$$

$$m_t(s) = q(s) + h(s)$$

$z(s) = - y_A T_w s$ can be considered for a non-flexible piping.

Solution is as follows:

$$q(s) = \frac{\alpha y(s)}{\alpha + 0,5 T_w y_A s} - (1-\alpha) \frac{n^*(s)}{\alpha + 0,5 T_w y_A s} \tag{25}$$

$$h(s) = - \frac{\alpha T_w y_A s}{\alpha + 0,5 T_w y_A s} y(s) + \frac{(1-\alpha) T_w y_A s}{\alpha + 0,5 T_w y_A s} n^*(s) \tag{26}$$

$$m_t(s) = h(s) + q(s)$$

$$m_t(s) = \alpha \frac{1 - T_w y_A s}{\alpha + 0,5 y_A T_w s} y(s) + (1-\alpha) \frac{T_w y_A s - 1}{\alpha + 0,5 y_A T_w s} n^*(s) \tag{28}$$

It is obvious from the equation (28) that an over-pressure turbine moment depends on 2 components, on a control mechanism opening and a speed change.

As the following applies:

$$m_t(s) = sT_a n^*(s) \tag{29}$$

$$\text{resp. } m_t(s) = (sT_a + e_c) n^*(s) \tag{30}$$

When taking the equation (29) into account, the following can be obtained:

$$\frac{n^*(s)}{y(s)} = \frac{\alpha(1 - T_w y_A s)}{0,5T_a T_w y_A s^2 + [\alpha T_a - T_w y_A(1-\alpha)]s + 1 - \alpha} \tag{31}$$

For the case of control, the most unfavorable case occurs if $y_A = 1$. Then the equation (31) can be obtained in the following form:

$$\frac{n^*(s)}{y(s)} = \frac{\alpha(1 - T_w s)}{0,5T_a T_w s^2 + [\alpha T_a - T_w(1-\alpha)]s + 1 - \alpha} \tag{31a}$$

When taking the equation (30) into account, the following can be obtained:

$$\frac{n^*(s)}{y(s)} = \frac{\alpha(1 - T_w s)}{0,5T_a T_w y_A s^2 + [(T_a + T_w y_A)\alpha + T_w y_A(\alpha - 1) + 0,5e_c T_w y_A]s + e_c + 1 - \alpha} \tag{32}$$

If $y_A = 1$ the equation (32) can be obtained in the following form:

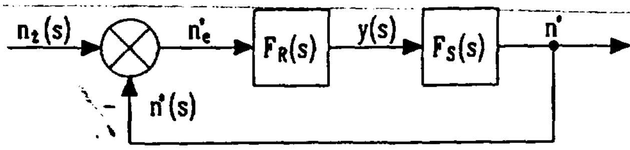
$$\frac{n^*(s)}{y(s)} = \frac{\alpha(1 - T_w s)}{0,5T_a T_w s^2 + [(T_a + T_w)\alpha + T_w(\alpha - 1) + 0,5e_c T_w]s + \alpha(e_c - 1) + 1} \tag{32a}$$

If in the equations (31), (31a), (32), (32a) we replace α with value 1, we can obtain equations valid for an equal-pressure turbine and we can make sure that the equation (31) corresponds to the equation (19) and the equation (32) corresponds to the equation (20).

1.5. Transfer Functions (19),(20),(31),(31a),(32),(32a)

define, in a truthful way, basic characteristics of a controlled system of a hydroelectric generating set which must be taken into account in a speed control considering any equal-pressure or over-pressure turbine. This controlled system also contains many non-linearities which were not considered to a full extent and which cannot be simplified any way, some of them can be linearized only in a certain neighbourhood of a working point, some turbines have even two control mechanisms (e.g. Kaplan turbines), some turbines operate in regions of large head fluctuations, etc. These facts should be considered correspondingly when designing a control circuit.

If a system transmission is designated as $F_S(s) = n^*(s)/y(s)$ and that of a controller as $F_R(s)$, a control circuit of a speed control can be expressed with a block diagram, as shown in fig.1.



$$\frac{n^*(s)}{n_z(s)} = \frac{F_R(s) \cdot F_S(s)}{1 + F_R(s) \cdot F_S(s)}$$

Characteristic equation for closed circuit : $1 + F_R(s) \cdot F_S(s) = 0$

Fig. 1

2. Mathematical Description of a Synchroneous Generator of a Hydroelectric Generating Set from the Point of View of its Control in a Large Capacity ES

A synchronous generator represents a complicated non-linear, multiple-parameter system, a reliable mathematical description of which results in a system of non-linear differential equations of a seventh order. Such kind of a system is difficult to realize for general purpose of control of its excitation and thus both the effect of transient processes in stator windings and in an absorber and the non-linear characteristic of a generator magnetic circuit are neglected in excitation control circuits.

We will consider the fact that multi-pole synchronous generators with salient poles are used in VE and PVE and when taking into account the fact that hydroalternators connected to ES are substantially of a lower capacity than that of ES, into which they operate, a design of models can then be based on a vector diagram of a synchronous machine with salient poles with simple replacements of ES taking into account only corresponding reactances of the generator circuits and ES. Fig.2 shows a vector diagram of a synchronous machine with salient poles.

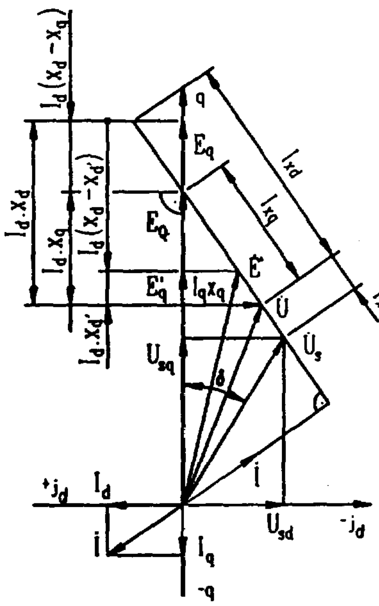


Fig.2

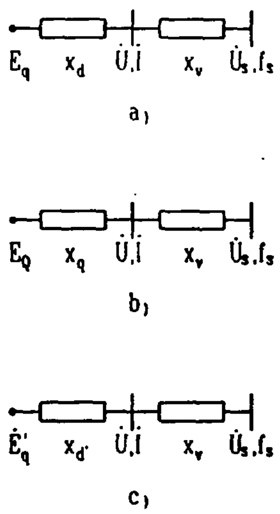


Fig.3

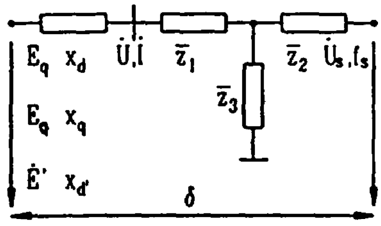


Fig.4

Fig.3 shows simplified models of a synchronous generator connected to ES through lines connected in parallel or one line with a total reactance of the line x_v. Fig.4 shows the same models of a synchronous generator as those in fig.3 but they are connected to ES through impedances $\bar{z}_1, \bar{z}_2, \bar{z}_3$.

2.1. A Simplified Model of a Synchronous Generator (SG) Shown in Fig.3a)

In this case, SG is modelled with an electromotive force proportional to an excitation current of SG (E_q), which has the same reactances in both the direct and quadrature axes ($x_d = x_q$).

This model especially meets the conditions of a synchronous machine with a solid hollow rotor. This model corresponds to a display of physical variables of SG and ES, which is shown in fig.2, in the case if $x_d = x_q$, whereas $E_Q = E_q$, because Id $(x_d - x_q) = 0$.

U ... terminal voltage of SG; U_s, f_s... voltage and frequency of a large capacity ES, respectively

$x_{ds} = x_d + x_v$; $x_{ds}' = x_d' + x_v$

x_d'... transient reactance of SG in a direct axis; δ ... load angle

The following applies for ES voltage:

$$\dot{U}_s = U_s e^{-jd} = U_s(\cos\delta - j\sin\delta) \tag{33}$$

The following applies for SG current:

$$j\dot{I}x_{ds} = E_q - U_s(\cos\delta - j\sin\delta)$$

$$\dot{I} = \frac{U_s\sin\delta}{x_{ds}} + j\left(\frac{U_s\cos\delta - E_q}{x_{ds}}\right) \tag{34}$$

$$I_q = \frac{U_s\sin\delta}{x_{ds}}\ ;\ I_d = \frac{U_s\cos\delta - E_q}{x_{ds}} \tag{35}$$

The following applies for an apparent power of SG:

$$\dot{S} = E_q \cdot \dot{I}^* = E_q(I_q - jI_d) = \frac{E_q \cdot U_s}{x_{ds}}\sin\delta - j\left(\frac{U_s\cos\delta - E_q}{x_{ds}}\right)E_q \tag{36}$$

Then, the following applies for an active power:

$$P = \frac{E_q U_s}{x_{ds}}\sin\delta = P_M\sin\delta;\quad P_M = \frac{E_q \cdot U_s}{x_{ds}} \tag{37}$$

The following applies for a reactive power:

$$Q = \frac{E_q^2 - E_q U_s\cos\delta}{x_{ds}} \tag{38}$$

The following applies for a terminal voltage of the generator:

$$U = [(E_q + I_d x_d)^2 + (I_q x_d)^2]^{0,5} \tag{39}$$

2.2. A Simplified Model of SG shown in fig.3b)

In this case, SG is simplified by a replacement for a virtual electromotive force (E_Q) and reactancy acting in a quadrature axis x_q. A vector diagram for SG with salient poles shown in fig.2 applies in this case.

The following relationship is valid between E_q and E_Q:

$$E_Q = E_q + I_d\,(x_d - x_q)$$

The following applies for ES voltage:

$$\dot{U}_s = E_Q - j\,\dot{I}x_{qs};\quad x_{qs} = x_q + x_v \qquad (40)$$

The following applies for SG current:

$$j\,\dot{I}\,x_{qs} = E_Q - \dot{U}_s e^{j\delta}$$

$$I = \frac{U_s \sin\delta}{x_{qs}} + j\left(\frac{U_s\cos\delta - E_Q}{x_{qs}}\right) \qquad (41)$$

$$I_q = \frac{U_s \sin\delta}{x_{qs}};\ I_d\ \frac{U_s\cos\delta - E_Q}{x_{qs}} \qquad (42)$$

The following applies for an apparent power:

$$\dot{S} = E_Q \dot{I}^* = E_Q\ (I_q - jI_d) = \frac{E_Q U_S}{x_{qs}}\sin\delta - j\left(\frac{U_s\cos\delta - E_Q}{x_{qs}}\right)E_Q \qquad (43)$$

The following applies for an active power:

$$P = \frac{E_Q U_S}{x_{qs}}\sin\delta;\quad Q = \frac{E_Q^2 - E_Q U_s \cos\delta}{x_{qs}} \qquad (44)$$

The following applies for a terminal voltage of SG:

$$\dot{U} = E_Q - j\dot{I}x_q;\ U = [(E_Q + I_d x_q)^2 + (I_q x_q)^2]^{0,5} \qquad (45)$$

2.3. A Simplified Model of a Synchronous Generator according to a Diagram Shown in Fig.4 Taking into Account the Alternative Expressed by a Transient Induced Voltage of a Generator $\dot{E}'$ and a Transient Reactance in a Direct Axis x_d'.

A transient induced voltage of SG can be expressed as follows:

$$\dot{E}' = E_q' + jE_d' \qquad (46)$$

Complex impedances of a line and SG in the considered case can be recalculated according to the following expressions:

$$\bar{z}_{11} = jx_d + \bar{z}_1 + \frac{\bar{z}_2 \cdot \bar{z}_3}{\bar{z}_2 + \bar{z}_3} = z_{11}e^{j\varphi 11} \qquad (47)$$

$$\bar{z}_{12} = jx_d' + \bar{z}_1 + \frac{\bar{z}_2}{\bar{z}_3}\ (jx_d' + \bar{z}_1 + \bar{z}_3) = z_{12}\ e^{j\varphi 12} \qquad (48)$$

The following applies for voltage and current vectors of SG:

$$\dot{U} = U_q + jU_d \tag{49}$$

$$\dot{I} = I_q + jI_d \tag{50}$$

$$\dot{I} = \frac{\dot{E}'}{\bar{z}_{11}} - \frac{U_s e^{j\delta}}{\bar{z}_{12}} \tag{51}$$

An apparent power of SG can be expressed as follows:

$$\dot{S} = \dot{U}\ddot{I}^* = (U_d I_d + U_q I_q) + j(U_d I_q - U_q I_d) \tag{52}$$

whereas the following applies for active and reactive powers:

$$P = U_d I_d + U_q I_q; \quad Q = U_d I_q - U_q I_d \tag{53}$$

Relationships between voltage and current in a stator winding of SG are determined from the following equation:

$$\begin{aligned} U_d &= - RI_d - x_q I_q \\ U_q &= - RI_q + E'_q + x'_d I_d \end{aligned} \tag{54}$$

R ... stator winding resistance (in our case $R \ll x_d$ is considered and thus it is neglected, whereas the components with R are eliminated from the equations).

A transient induced voltage in q axis depends on excitation currents of SG:

$$E'_q = x_{ab} \cdot I_b + (x_d - x'_d) \cdot I_d \tag{55}$$

whereas $x_{ab} \cdot I_b = E_q$

$$E'_q = E_q + (x_d - x'_d) I_d \tag{55a}$$

I_b... SG excitation winding current;
x_{ab}.. mutual reactance of excitation and stator windings

E'_q can also be expressed with an excitation winding flux φ_b:

$$E'_q = \frac{L_{ab}}{L_b} \varphi_b \omega \tag{56}$$

φ_b... magnetic flux coupled with an excitation winding
L_{ab}.. mutual inductance of excitation and stator windings
L_b... excitation winding inductance
ω ... angle velocity

Referring to a differential equation of SG excitation circuit:

$$U_b = R_b I_b + \frac{d\varphi_b}{dt} \tag{57}$$

and using the equations (55), (56) the following can be derived:

$$\frac{d\psi_b}{dt} = U_b - \frac{1}{T}\psi_b + \frac{1}{K_b\omega}(x_d - x_d')\, I_d \tag{58}$$

if $T_b = \frac{L_b}{R_b}$; $K_b = \frac{L_{ab}}{R_b}$

U_b... SG excitation voltage; R_b ... excitation winding active resistance

If the equation (58) is further processed, the following can be obtained:

$$T_b \frac{dE_q'}{dt} = U_b \cdot K_b \cdot \omega - E_q' + (x_d - x_d')I_d \tag{59}$$

Transient induced voltage in d axis can be defined as follows:

$$E_d' = \frac{x_d - x_d'}{z_{11} - (x_d - x'_d)\sin\varphi_{11}} \left[E_q'\cos\varphi_{11} + \frac{z_{11}}{z_{12}} U_s\cos(\delta + \varphi_{12})\right] \tag{60}$$

Defining the equation (51) for a stator current in a component form, equations for generator current components can be obtained after some modifications:

$$I_q = \frac{E_q'\cos\varphi_{11} + E_d'\sin\varphi_{11}}{z_{11}} - \frac{U_s\cos(\delta + \varphi_{12})}{z_{11}}$$

$$I_d = \frac{E_d'\cos\varphi_{11} - E_q'\sin\varphi_{11}}{z_{11}} - \frac{U_s\sin(\delta + \varphi_{12})}{z_{12}} \tag{61}$$

For a module of a stator current and a terminal voltage of SG the following can be stated:

$$U = (U_d^2 + U_q^2)^{0,5}; \quad I = (I_d^2 + I_q^2)^{0,5} \tag{62}$$

The types of models mentioned above in sections 2.1, 2.2, 2.3 of a synchronous generator and its connection to a large capacity ES for the purposes of a control system of a hydroelectric generating set can be completed, as required, with other parts which were not taken into account (damping rotor winding of SG, etc.). See also e.g. [1].

2.4. Synchronous Machine (Momentum) Equation of Motion

An equation of motion is defined by the following expression:

$$J\frac{d\Omega}{dt} = M_T - M \tag{63}$$

J...moment of inertia
Ω...mechanical angle velocity
M_T..driving turbine moment

M...electrical moment (including a loss moment)

$$\omega = n_p \Omega \qquad (64)$$

ω... electrical angle velocity of SG; n_p.. number of pole pairs of SG

If $n_p . J . \Omega_0^2 = T_m$, then the equation (63) is changed into the following form:

$$\frac{T_m}{\omega_s} \frac{d\omega}{dt} = M_T \omega_0 - M\omega_0 \doteq P_T - P \qquad (65)$$

if SG operates in a parallel operation in ES, then

$$\omega = \omega_s + \frac{d\delta}{dt} \qquad (66)$$

ω_s...synchronous angle velocity of SG, δ...load angle of SG

then $\frac{d\omega}{dt} = \frac{d^2\delta}{dt^2}$

if $T_m/\omega_s = T_j$, the equation (63) will be expressed as follows:

$$T_j \frac{d^2\delta}{dt^2} + P = P_T \qquad (67)$$

An equation of motion expressed using the equation (67) is used very often. Its solution very strongly depends on that what kind of a model is used to express an electric capacity P, but at the same time also on that what kind of expression is used to express turbine power output (P_T). This relation expresses connection of a turbine and a generator as a single unit the control of which must be designed as a uniformly controlled system.

2.5. A Stability of a Synchronous Generator in Cooperation with a Large Capacity ES

Let's consider a simplified model of SG connection to a large capacity ES according to a scheme shown in fig.3a.

More over, we will start from the equation of motion (67) in which the synchronous capacity will be determined from the equation (37) and it will be completed with an asynchronous component expressed by the following equation:

$$P_{as} = D \frac{d\delta}{dt} \qquad (68)$$

For an excitation circuit, we will use knowledge mentioned in the equations (55) to (62) whereas instead of the designation ωK_b we will introduce SG no-load amplification K_{G0}, which is defined as follows:

$$K_{Go} = \frac{\text{stator no-load voltage steady value}}{\text{rotor excitation voltage steady value}} = \frac{E_{qo}}{U_{bo}} = \frac{I_b L_{ab}\omega_s}{I_b R_b} = \frac{L_{ab}\omega_s}{R_b} \quad (69)$$

The equation (59) will be expressed in the following form:

$$U_b K_{Go} = E_q + T'_{do}\frac{dE_q}{dt} + T'_{do}\frac{dI_d}{dt}(x_{ds} - x'_{ds});\ T'_{do} = L_b/R_b = T_b \quad (70)$$

The following can be written for linearized equations (67) and (70):

$$T_j \frac{d^2\delta}{dt^2} + D\frac{d\delta}{dt} + \frac{E_q U_s}{x_{ds}} \sin\delta = P_T \quad (71)$$

$$\text{when } P = \frac{E_q \cdot U_s}{x_{ds}} \sin\delta \rightarrow \Delta P = \left(\frac{\partial P}{\partial\delta}\right)\Delta\delta + \left(\frac{\partial P}{\partial E_q}\right)\Delta E_q = \frac{E_q U_s}{x_{ds}} \cos\delta_o \Delta\delta + \frac{U_s}{x_{ds}} \cdot \sin\delta_o \Delta E_q$$

$$T_j \frac{d^2\Delta\delta}{dt^2} + D\frac{d\Delta\delta}{dt} + \frac{E_q U_s}{x_{ds}} \cos\delta_o \Delta\delta + \frac{U_s}{x_{ds}} \sin\delta_o \Delta E_q = \Delta P_T \quad (72)$$

$$\Delta U_b \cdot K_{Go} = \Delta E_q + T'_{do}\frac{d\Delta E_q}{dt} + T'_{do}(x_{ds} - x'_{ds})\frac{d\Delta I_d}{dt} \quad (73)$$

$$I_d = \frac{U_s\cos\delta - E_q}{x_{ds}} \rightarrow \Delta I_d = \frac{\partial I_d}{\partial\delta}\Delta\delta + \frac{\partial I_d}{\partial E_q}\Delta E_q = -\frac{U_s\sin\delta_o}{x_{ds}}\Delta\delta - \frac{1}{x_{ds}}\Delta E_q$$

$$\Delta U_b \cdot K_{Go} = \Delta E_q + T'_{do}\frac{d\Delta E_q}{dt} + T'_{do}(x_{ds} - x'_{ds})\frac{d}{d_t}\left[-\frac{U_s\sin\delta_o}{x_{ds}}\Delta\delta - \frac{1}{x_{ds}}\Delta E_q\right] \quad (74)$$

If we express:

$$T_{dz} = T'_{do}\, x'_{ds}/x_{ds};\ T_\delta = \frac{T'_{do} U_s (x_{ds} - x'_{ds})}{x_{ds}} \cdot \sin\delta_o \quad (75)$$

$$B_p = \frac{\partial P}{\partial E_q} = \frac{U_s}{x_{ds}} \sin\delta_o;\ C_p = \frac{\partial P}{\partial\delta} = \frac{E_q U_s}{x_{ds}} \cos\delta_o \quad (76)$$

the equations (72) and (74) can be expressed in the following form:

$$(\Delta U_b + T_\delta \cdot s \cdot \Delta\delta/K_{Go})\, K_{Go}/(1+T_{dz}\cdot s) = \Delta E_q \quad (77)$$

$$(T_j s^2 + D_s + C_p)\Delta\delta = \Delta P_T - B_p \Delta E_q \quad (78)$$

and a structural scheme of a synchronous machine operating into a large capacity ES shown in fig.5 can be designed.

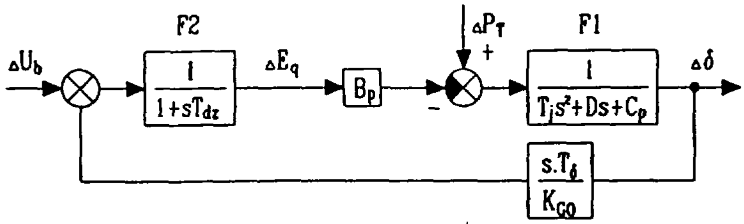


Fig.5

The following applies for the considered system:

$$\Delta\delta = \frac{1 + sT_{dz}}{H(s)}\Delta P_T - \frac{K_{Go}B_p}{H(s)}\Delta U_b \qquad (79)$$

$$\text{where } H(s) = T_j T_{dz} s^3 + (T_j + DT_{dz})s^2 + (D + T_\delta B_p + C_p T_{dz})\, s + C_p \qquad (80)$$

H(s) is a characteristic equation of the considered linearized model of a synchronous generator connected to a large capacity ES in a reactance x_v (fig.3a).

A well-known fact results from the equation (79), i.e. if ΔP_T increases, $\Delta\delta$ increases and if ΔU_b increases $\Delta\delta$ decreases.

More detailed discussion of a solution to the considered linearized model stability, studying the equation (80), discussion of further complicated models of work of SG in large ESs cannot be covered in this entry. However, the author's effort was to partially clarify this problem in a limited extent at least.

2.6. A Stability of SG with a Voltage Controller Including Consideration of Feedback Stabilization Loops (SSV-PSS) in Cooperation with a Large capacity ES

A considerable attention is paid to these issues by experts both in our country and abroad. We would like to point out to the materials [2], [3] by our scientists.

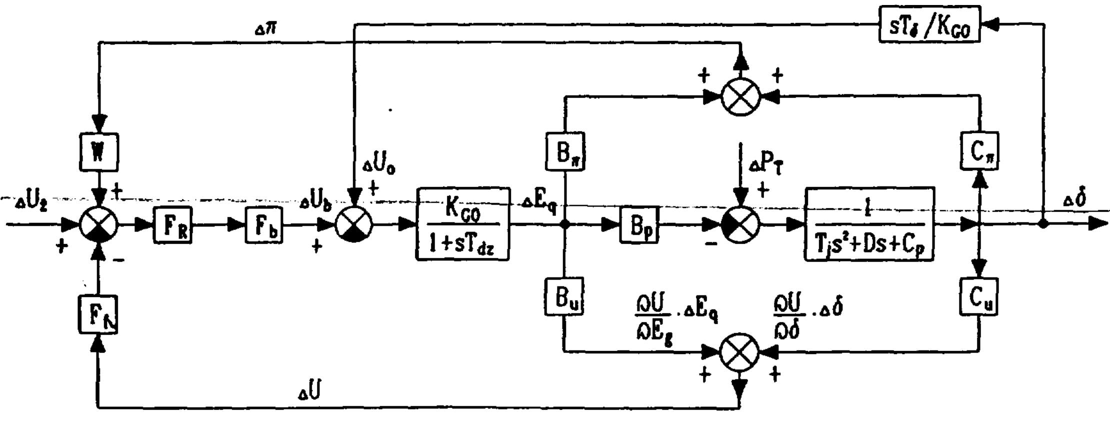


Fig.6

A structural scheme of a linearized model of SG operating into ES considering stabilizing feedback loops with a voltage controller with a general transmission $F_R(s)$ is shown in fig.6. This scheme includes a structure of a linearized model shown in fig.5.

The following applies for a small change of a terminal voltage of SG in the working point (E_{qo}, δ_o) neighborhood:

$$\Delta U = \frac{\partial U}{\partial \delta} . \Delta\delta + \frac{\partial U}{\partial E_q} \Delta E_q = C_u \,\Delta\delta + B_U \Delta E_q \tag{81}$$

where B_U and C_U can be calculated from the equation (39), into which the expressions (35) are inserted instead of I_d, I_q.

The following can be written for a small change in a stabilizing signal π in the working point neighborhood:

$$\Delta\pi = \frac{\partial\pi}{\partial\delta} \Delta\delta + \frac{\partial\pi}{\partial E_q} \Delta E_q = C\pi \Delta\delta + B\pi \Delta E_q \tag{82}$$

π... stabilizing signal (e.g. generator capacity, slip, ...)
w... transmission function of a filter and a stabilization algorithm of control

$$U_{stab} = w\Delta\pi = w\Delta\delta C_\pi + w\Delta E_q B_\pi \tag{83}$$

A characteristic equation of the control circuit shown in fig.6 has the following form:

$$H(s) = T_j T_{dz} s^3 + (T_j D T_{dz}) s^2 + (D + C_p T_{dz} + T_\delta B_p) s + C_p + (wc_\pi - F_f U_u) F_R F_b B_p K_{Go} \tag{84}$$

C. Conclusion

The main goal of this entry was to provide a complex mathematical description of a system in which a conversion of a potential energy of water into a kinetic energy, a kinetic energy into a mechanical one and a mechanical one into an electrical one takes place in two closely related phases.

The first phase takes place in a hydraulic circuit with a water turbine the shaft of which is connected with a rotor of SG. This phase is described in general for a basic principle of an energy conversion in any turbine the selection of which is done of two basic types of turbines (equal-pressure and over-pressure ones) and results through a description of static and dynamic characteristics into an expression of transmissions of a controlled system in which a dynamic behavior described using differential equations is expressed in an operator form and a general characteristic equation of a control circuit of a hydroelectric generating set is written. With new realization objectives of control systems of a hydroelectric generating set, a special attention should be paid to a non-linear function $Q=f(Y)$ for an entire range of water head fluctuations. Meeting this requirement will result in a use of a corresponding configuration of adaptive speed controllers the parameters of which should be changed depending on a turbine opening and a head.

The other phase takes place in SG connected to ES or an electrical load, respectively. This phase is described using differential equations of a stator circuit of SG connected to ES, a differential equation of an excitation circuit including mutual relationships of both the circuits and an equation of motion of SG and results into an expression of a characteristic equation of a control circuit which also contains stabilizing feedback.

A structural scheme of a linearized model of SG operating into ES taking into account stabilizing feedback is designed for a small change in a terminal voltage ΔU of SG and a small change in a stabilizing signal $\Delta \pi$.

It would be preferable, especially for larger hydroelectric generating sets, to make use of introduction of a stabilizing feedback from a large change in a stabilizing signal (a parallel line failure switching off, thus substantially changing ES conductivity and SG capacity, too), whereas the stabilizing signal would be derived from. SG capacity and its first derivation. Certainly provided that a corresponding stabilization filter and a special control algorithm (W_X) are used.

From the a.m. models of first and second phases of energy conversion, it is clearly visible that a turbine control and SG control cannot be separated from each other into independent units because these two components are closely connected into one unit with an equation of motion of a hydroelectric generating set which is the most expressly shown up in a control of transient processes where the most complicated operational states must be controlled.

Enhanced demands for control quality and stability of hydroelectric generating sets in ES will also require, except the use of the newest exact methods, introduction of simulation models of hydroelectric generating sets into a real life for a design of which the knowledge mentioned in this entry can be used.

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SK97K0334

The Most Important Structures Utilizing Primary and Secondary Hydroenergetic Potential for Electric Energy Production

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INTRODUCTION:

Technically usable primary hydroenergetic potential in the area of the Slovak Republic amounts to 7.361 GWh per year. Actually, the hydroenergetic potential (HEP) is used only for 52.6%.

Pumped storage plants utilize a secondary HEP. They gain electric energy from potential energy of water, repumped from a lower reservoir into an upper one.

The largest source in the Slovak Republic utilizing a primary HEP, is a hydroelectric power plant Gabčíkovo. The largest source utilizing a secondary HEP is a pumped storage plant Čierny Váh.

Hydo Power Project Gabčíkovo

Construction of the hydroelectric power plant Gabčíkovo started in 1978 as a part of a system of hydro power projects Gabčíkovo - Nagymaros (SVD G-N).

After the Hungarian part interrupted its work in SVD G-N, a decision was made to put a hydro power project Gabčíkovo, in a high level of construction at that time, into operation in 1991 in a supplementary way in the area of the Slovak Republic. The actual stage was realized according to the original plan. Damming of the Danube was moved from a Dunakility profile upwards a river flow into a Čunovo profile, in which both the banks belong to the Slovak Republic.

The first hydroelectric generating set was put into operation in October 1992. Eight hydroelectric generating sets have been in operation in hydroelectric power plant (HPP) Gabčíkovo since December 1995.

Main objects of the Gabčíkovo hydroelectric power plant:
- Hrušov reservoir
- intake channel
- Gabčíkovo stage
- waste channel

Hrušov Reservoir

The Hrušov reservoir is created by heaving the Danube level by a supplementary damming at Čunovo. Its purpose is to accumulate Danube flows with a follow-up use of water in Gabčíkovo plant and also to create a deep water shipping path for shipping. An available content of the reservoir is 35 mil. cubic meters. A temporary design of the Hrušov reservoir consists of a right hand dam of the reservoir on the right bank of the Danube, an intake object to a Mošon branch, a weir in an inundation, Čunovo hydroelectric power station at the weir, a weir and an auxiliary gate, a weir on a by-pass, Danube river channel damming, and a left hand dam on the left bank of the Danube.

Intake Channel

The intake channel dams follow up with the dams of Hrušov reservoir and finish at the Gabčíkovo plant. The channel is 17 km long, its width varies in a range from 267 to 737 m at its bottom. Water is 7.3 to 14.3 m deep in the channel. Watertightness of the channel is provided with an asphalt-concrete sealing of dam slopes and a foil sealing of the bottom. The channel is dimensioned to a maximum rate of flow 5,300 m^3/s. An available content within a level swing of 1 m is 11 mil. cubic meters.

Gabčíkovo Stage

The stage consists of two main objects - a hydroelectric power plant and gates. Its purpose is to utilize the created head for electricity production and to overcome a difference between levels in front of and behind the stage by vessels in the gates. A total number of eight hydroelectric generating units with a total installed capacity 720 MW is installed in the plant.

Waste Channel

The waste channel discharges water from the Gabčíkovo stage into the original Danube bottom. It is 8.2 km long. In the same way as the intake channel, it is also designed as a shipping path.

Technological Part

8 hydroelectric generating sets are installed in four double-blocks in a machine room of the hydroelectric power plant (VE).

Basic technical data:

- installed capacity	8 x 90 MW
- production in an average aqueous year	2,650 GWh
- number of hydroelectric generating sets	8
- turbine flow	8 x 413 - 636 m^3/sec
- head	12.9 - 24 m

The hydroelectric generating sets are arranged vertically, a synchronous generator is connected with a turbine by means of a flange coupling. A support bearing is located directly on a raised turbine head. The shaft is supported in two guide bearings, in a lower bearing in a turbine head extension and in an upper bearing below the generator rotor. Location of the upper guide bearing enabled an umbrella design of the generator to be used.

Kaplan turbine has a runner diameter 9.3 m. The runner has four blades of a special high strength stainless steel.

The hydroelectric generating sets belong to the largest ones manufactured in the world.

Power output of the generators is led into two voltage levels from six generators through an encapsulated switchgear 400 kV into a knotty line Podunajské Biskupice - Győr and from two generators through an external switchgear 110 kV into two lines to Dunajská Streda. Both the voltage systems are interconnected with an autotransformer.

VE Gabčíkovo Operation

VE Gabčíkovo is directly controlled from a dispatching centre of Vodné elektrárne Trenčín. The individual hydroelectric generating sets are fully automatic. Control is provided by a control and information system of the plant. Operation control of the sets must ensure a safety of vessels present in the intake and waste channels in a mode of non-permanent flow resulting from a change in a flow through turbines. Thus the plant can start from a zero to a full capacity in 30 to 32 minutes. In the case of an emergency shutdown of the sets (loss of voltage in 400 and 110 kV switchgears), the sets are switched into an energy-free operation and water flow through turbines is without energy utilization. An energy-free operation can last for 30 minutes. The plant can operate in a peak load operation because there is no balance reservoir built below the plant. The operation of the plant is continuous and basically it is governed by a flow in the Danube which is also affected by an operation of a hydroelectric power plant in Austria. Operation rules are set in manipulation instructions and are adopted to shipping requirements. The manipulation instructions define levels above the plant in relation to the Danube flow. The plant operation must provide meeting the level within limits ±15 cm. In a period of low flows below 1,200 m^3/sec, limits are ±4 cm.

Small hydroelectric power plants Mošoň and S VII belong to the Gabčíkovo hydro power project.

The plant produced 9,163 GWh of electricity from the beginning of its operation till the end of 1996.

Pumped Storage Plant Čierny Váh

The construction of the pumped storage plant (PVE) Čierny Váh started in 1976 and it was put into operation at the end of 1980.

The main goal of the PVE Čierny Váh is to meet the control functions of an electrification system of the Slovak Republic in conditions of UCPTE, a substitute function in the cases of unexpected power outages and a planned electricity production from repumping.

Main objects of PVE Čierny Váh:
- upper reservoir
- underground supply conduits and a communication tunnel
- surface hydroelectric power plant
- lower reservoir

Upper Reservoir

The upper reservoir was built as an artificial one without a natural inflow on a plane with an irregular shape between the valleys of Biely Váh and Čierny Váh, at an elevation of more than 1,150 meters above sea level. The reservoir is created by excavations and fill from limestones and dolomites.

Water slope of the reservoir with a slope 1 : 2 and the bottom of the reservoir have a jacket asphalt-concrete sealing. Because of a check of possible leakages through the asphalt-concrete sealing, a drainage system led into a control tunnel located along the entire circumference of a bottom of the water slope was built. Rakes, hydraulically controlled high pressure valve gates and auxiliary stop logs are installed in the inflow object of the upper reservoir. An available capacity of the reservoir is 3.7 mil cubic meters and a water level fluctuation is 25 m between the elevations 1,160 and 1,135 meters above sea level.

An access road 7.5 km long leads form Svarín settlement to the upper reservoir.

Underground Supply Conduits and a Communication Tunnel

The supplying conduits represent a connection hydraulic route between the upper and lower reservoirs. The upper reservoir is connected with a hydroelectric power plant with three underground armored supply conduits. Internal diameter of the conduits is 3.8 m and the thickness of a steel armor is from 12 to 43 mm. One conduit provides water supply for two hydroelectric generating sets. A conduit is ended with a ball coupler which provides branching of a single conduit to two turbines and two pumps.

Communication between the lower and upper reservoirs is provided by a communication tunnel whereas a lift is installed in its sloped section.

Hydroelectric Power Plant

A building of the plant is a part of a dam of the lower reservoir and consists of a machine room, assembly block, a block for inspection of transformers and a neighboring operation building.

A lower structure and also water side representing a part of a body of the lower reservoir dam are of a massive concrete, the upper building has a steel structure.

Lower Reservoir

A dam of the lower reservoir is a concrete, gravitation one with an additional fill on an air side. The dam is 375 m long and a double-field outlet object and a bottom outlet are a part of it.

Lower reservoir slopes are arranged in a slope 1 : 5. reinforcement of the slopes is from aggregates below which there is a textile filtering layer.

An available volume of the reservoir is 3.7 mil. cubic meters and a water level fluctuation is 7.45 m between the elevations 726 and 733.45 meters above sea level.

Technological Part

Six repumping vertical hydroelectric generating sets in a three machine arrangemet - a motorgenerator, a turbine, a pump - are located in three double-blocks in the machine room of the plant.

Basic technical data:

- installed capacity	6 x 122.4 MW + 0.768 MW
- yearly production	1,281 GWh
- number of hydroelectric generating sets	6
- number of domestic hydroelectric generating sets	1
- turbine flow	3 x 30 m^3/sec
- pump flow	6 x 22 m^3/sec
- upper reservoir volume	3.7 mil. m^3
- max. head	434 m
- peak time	5.71 hour
- pumping time	7.78 hour
- repumping cycle efficiency	74.36%

A synchroneous motorgenerator is directly connected to a Francis turbine. The motorgenerator is supported in two guide bearings and in a support bearing located above a rotor.

The Francis vertical turbine is supported in the upper and lower segment self-lubricated bearings. A turbine shaft is a two-part one. Its upper part connects a turbine wheel with a motorgenerator shaft, whereas the lower part goes through a draft tube and connects a turbine wheel with a claw clutch of the pump. Guide blade pivots are supported in a self-lubricating housings which prevent water from being polluted with crude oil products. A hydraulically controlled claw clutch is located between a turbine and a pump.

The accumulation pump is a single-intake, two-stage one. A supporting bearing is designed in combination with a guiding one and is placed on the upper cover. A lower guide bearing is placed on an elbow of the draft tube.

The control equipment consists of distributor servos, a governor pumping unit, an electrodynamic governor. Ball gates with diameter 1.6 m, designed for closing up to a full flow on both directions of water flow, are arranged in front of a spiral casing gate and behind the output from a pump side.

A small Kaplan turbine with a generator with a capacity 768 kV is designed to utilize natural water flows of Čierny Váh and also to provide internal electricity consumption, especially for starting the main hydroelectric generating units at a loss of voltage of the internal-consumption.

The motorgenerator capacity is output into 15.75 kV switchgear, through underground channels by a block transformer in 400 kV switchgear from there. The switchgear is connected to Liptovská Mara switchgear through an overhead line.

PVE Čierny Váh Operation

PVE is directly controlled by Slovenský energetický dispečing Žilina (the Slovak power dispatching centre in Žilina). Operation of respective hydroelectric generating sets is fully automated. Control is provided by a control and information system of the plant. Operativeness of setting the PVE into operation is highly appreciated from the point of view of a dispatcher's control. Start up from a rest to a full capacity in a turbine mode of operation of the whole PVE takes 70 seconds, start up from a rest into a pumping mode of operation takes about 120 seconds.

From putting the PVE into operation till the end of 1996, the hydroelectric generating sets were in operation 145,269 hours in total, including 53,332 hours in a turbine mode of operation, 70,293 hours in a pumping mode of operation ,and 21,644 hours in a compensation mode of operation. Whereas they supplied 5,346 GWh in the mains and they consumed 6,933 GWh of electricity for pumping. A number of start ups, which has reached the value 78,441 since putting into operation, gives an idea on utilization of the plant for the system control. Out of which, the sets started up 36,706 times into a turbine mode of operation, 30,632 times into a pumping mode of operation and 11,103 times into a compensation mode of operation.

Utilization of the plant has not been uniform all the time but the highest values were reached in 1989 when a yearly production reached the value of 497 GWh. On the contrary, the lowest yearly production was in 1996 when it reached the value of 165 GWh.

Conclusion:

Hydroenergetic potential is a primary source of energy which is recyclable, i.e. unexhaustable and also ecologically the most tolerable. No wastes or pollution, respectively are produced in its utilization, there are no requirements for mining facilities or capacities. Construction of hydro power projects and their utilization bring more benefits than damages.

4,478 GWh were produced in hydroelectric power plants in the Slovak Republic in 1996. This production represents 15,51% of total consumption of ES in the Slovak Republic.

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Progressive Technologies, Modernization of HPPs Aimed at Rationalization in a Use of a Hydroenergetic Potential and Environment Protection.

Ing. Pavol Sabela et al.

Technical equipment of hydroelectric power plants (HPPs) built in river basin Váh, middle Hron and on Danube from 1936 to 1996 corresponded in its design to the given technology level and requirements for their functions - energy utilization of a hydroenergetic potential and water functions of waterworks. They were built as run of river, storage and peak-load power stations. Starting with Liptovská Mara HPP (1975), construction of pumped storage sets (2 x 49 MW with Deviazo turbines) started. Two machine sets (Kaplan turbines with synchronous generators) were installed in water-power plants. A three machine set arrangement (a synchronous generator, Francis turbine and a two-stage pump with a claw clutch) was installed in the pumped storage plant Čierny Váh (1980). The sets in HPP Tvrdošín, HPP Bešeňová, MVE Veľké Kozmálovce, MVE Gabčíkovo and MVE Mošon are installed horizontally in combination with asynchronous generators. 73 sets with a total installed capacity 2,268.76 MW are operational at present. A schedule of realization is shown in charts No.1 and 2 in the annex to this entry. Two hydroelectric power plants - Žilina and Čuňovo - are being built in 1997.

ČKD Blansko, Škoda Plzeň, former ZPA Čakovice, with older water-power plants ČKD Praha, but also Siemens and former BBC are prevailing manufacturers of equipment for hydroelectric power and pumped storage plants. A design of speed governors, excitation sets of generators and control elements of sets and automatic systems of the equipment corresponded in a similar way to a technical development, too. The original speed governors were of an oil-hydraulic type, excitation sets by BBC company, Škoda Plzeň (oil-pressure governors, MRNG - magnetic governors). Automatic systems underwent a sequential expansion of partial relay automatic systems up to a complex relay operating automatic system of a set. Capacity of HPPs and PSPs (pumped storage plants) is led into different voltage systems from LV (0.5 MW machine of HPP Tvrdošín), 22 kV, 110 kV up to 400 kV systems with 6 sets of PSP Čierny Váh and 6 sets of HPP Gabčíkovo. In the same ways as the production equipment, the equipment of LV distribution system, direct current distribution system, HV and VHV switchgears of HPPs and PSPs are also of a different design and from different manufacturers.

Requirements for operational functions of hydroelectric power plants were also developed with the development of a power system of the Slovak Republic, building new sources (thermal and later nuclear plants). Of the function of run of river HPPs or peak load HPPs, respectively, controlling functions, functions of a system reserve (PSP Čierny Váh) took over and since connection to UCPTE in October 1995, functions in the area of primary and secondary controls at use in a peak mode of operation of selected HPPs in a daily load diagram have been defined.

Together with changes in requirements for functions of HPPs, a necessary process of repairs and maintenance of HPPs and PSPs and a process of modernization and updating of equipment have also occurred; requirements for environment protection, mostly protection of rivers against crude oil products, have appeared. Efforts to make the use of hydroenergetic potential more efficient - an increase in efficiency of production of a primary electrical energy (optimalization of operational parameters of sets, but also a change in their hydraulic profiles) and also reduction of the actual consumption for productional and non-productional purposes (utilization of idle heat of generators and power transformers), have occurred.

In 60s and 70s, a global concept in directing a technical design of equipment for HPPs was unified, a group control of HPP sets was accepted and a development of dispatching and information systems, and later also a control system, of HPPs of Váh cascade has started. Rules for unified system of maintenance and repairs of equipment - technical extent of operational maintenance, inspections and repairs - were established. Dropout capability of equipment was unified and methods of diagnostic and warning measurements for evaluation of a condition and residual durability of crucial points of equipment were started. But a technical diversity of the equipment required an individual approach to a specification of an extent of repairs and modernization, however the following main priorities of this process have been established, they were proved to be the correct ones in operational practice:

- an increase in operational reliability of equipment of HPPs
- an increase in efficiency of a conversion of hydroenergetic potential
- a decrease of rates of personnel of HPPs
- a change to a remote information and control system enabling an effective operation of Váh cascade

in ES system respecting hydraulic relationships of HPPs of the cascade
- an increase in operability and readiness of the sets
- an increase in environment protection
- an introduction of methods of diagnostic and warning measurements as a necessary part of making the process of maintenance and repair of the equipment more efficient.

A phase I of modernization of equipment of HPPs, replacement of voltage governors - use of analog tyristor governors of RNG type (Škoda Plzeň), a complex automation with consequent analog autooperators of HPP, introduction of remote measurement, indication and control of HPP from a centre - a company dispatching centre of Vodné elektrárne Trenčín - were finished in 70s.

In 80s, a process of replacement of relay automatic systems with ZEPALOG systems (fixed logic) was started, a computerized processing of maintenance programs was introduced, use of computer technology of RPP or SMEP types, respectively in the area of control of technologic processes in HPP and also in the area of an automated control of a company was started. In the area of control processes, 90s are characterized by introduction of digital technology, use of microprocessors in the area of control systems for turbine speed, excitation of generators, sequential automates of sets as a part of distributed control systems of units of equipment of HPPs and also group governors of units of HPPs and PSPs.

Use of a microprocessor technology in the area of dispatching and control systems was at the same time also a qualitative step in a control of HPP and PSP as a unit towards ES system. An information and control system was completed with a corrector of optimalization of a cascade and the present level of operation control of HPP and PSP correspond to a European standard including providing control functions of HPP and PSP to an electric system.

Certainly, introduction of automation, development of dispatching and control technology required, and still requires, a corresponding level of a basic production and distribution equipment of HPP and PSP - a change to switching equipment with SF_6 medium, to vacuum LV and HV switching equipment, motor driven LV and HV disconnectors, arresters of ZNO types (VHV and HV), replacement of older types of transformers, modification of governors, distribution transformers, systems of electric protections (continuous process of replacement of relay types and electronic protections ZPA), introduction of a system of total measurement of electricity within SE, a.s. (DG C500).

In 1984 - 1995, analog and microprocessor governors of turbine speed were completed with circuits for a function of a primary control in compliance with UCPTE conditions and HPPs, as a unit, were adopted to a governor of ES system, too. Diagnostic of insulation systems of generators and components of electric equipment including measurement of earthing and protection systems of HPP was brought to a standard level. Development of a machine diagnostic has started perspectively. Vibrometric measurements with an analysis of nodes of sets have also been introduced in addition to standard control measurements. Permanent and close co-operation with both technical universities in the Slovak Republic (STU Bratislava, VŠDS Žilina) and manufacturers of equipment is a basis for development of diagnostic methods.

Designs of a replacement of composite materials of axial segments with foils of high-molecular polyethylenes have also proved in practice (reduction of loss in bearings, increase in a tightness of distributors - an importance at a time of accumulation, including introduction of control measurements, introduction of monitoring in the area of vibrations of nodes of sets. Maintenance, repair and upgrading of equipment in HPPs and PSPs strictly follows an increase in environment protection and a requirement for improvement of the existing state has a natural priority over an effective technical design.

Among the most important results, the following should be mentioned: introduction of oil separators in all HPPs and PSPs for treatment of waste water from HPPs and PSPs, introduction of a lubrication-free support of lower parts of turbines, continuous tightness control of turbine wheel hubs and replacement of original collar sealings of pins of turbine blades with doubled sealings, continuous periodical monitoring of waste water from HPP and check for a contents of crude oil products, construction of sealed tanks below external power transformers and finished construction of treatment plants for rain water from transformer areas, preparation of a replacement of transformers HV, LV for internal consumption of the equipment in HPP - a change to dry transformers, a strict use of sealed measuring oil transformers or a change to transformers with SF_6 medium in 110 kV switchgear, a change from 110 kV low-oil power disconnectors to disconnectors with SF_6 medium, finishing the construction of treatment plants for waste water from HPPs and PSPs in the whole extent of operated hydroelectric power plants, creation of conditions and a permanent control of manipulation with dangerous wastes resulting in a process of maintenance and repair including their disposal in compliance with a valid legislation, permanent cooperation with a water management operator and providing a specified storage of wastes from treatment of inlets of HPPs and PSPs including modernization of cleaning machines of the inlet objects. The level reached in the area of environment protection and a condition of equipment in HPPs and PSPs are also a prove of a positive response of results from the control activities of respective institutions in environment protection which state a substantial increase of the condition within the last five years which binds to strictly continue in the accepted program.

Main goals in the area of operation, repairs and modernization of HPPs and PSPs for future period of time are given by the goals of changes being carried out in SE, a.s. projected into the conditions of operation of HPPs and PSPs. The goal is to have HPPs and PSPs operated with a minimum operational personnel which requires to finish a process of modernization of automatic systems and dispatching control technology with an emphasis placed on the area of sensors and power control elements of sets and distribution equipment, to finish building of an effective monitoring of vibrations of nodes of the sets of HPPs and PSPs (Kompass system by Bruel and Kjaer company used in HPP Gabčíkovo, the systems realized in HPPs Tvrdošín, Bešeňová, Nosice, Ilava, Hričov, Považská Bystrica, etc.), to finish building of a remote control through sequences of distribution equipment of HPPs and PSPs (with operator-free plants), introduction of technical equipment into the area of protection of objects of HPPs and PSPs (electronic protection built in HPP Gabčíkovo and PSP Čierny Váh), development of diagnostic methods and warning measurements as means for increasing the efficiency of repair and maintenance processes - to continue in a process of enforcement of a sufficiently effective maintenance of equipment in HPPs and PSPs keeping their high operational reliability.

— A process of modernization of nodes of equipment of HPPs and PSPs has been extended lately to cover all pieces of equipment of HPP aimed at an increase in effectiveness of HPP as a unit. Turbine wheels of selected HPPs were replaced in the past, replacement of impellers of pumps of machines in PSP Čierny Váh started at present and a complex modernization of our oldest HPP Ladce (1936) is planned aimed at an increase in absorption capacity of water turbines with an increase in their efficiency. The process of increasing the efficiency of the existing units without substantial construction changes in blocks of turbines gives also an economic acceptability to the mentioned approaches from the point of view of both the gained installed capacity and electrical energy production compared to an option of building a modern hydroelectric power plant (MVE) and it is also more acceptable from the point of view of environment protection than newly built MVEs.

All of the technical changes, a process of increasing the use of a hydroenergetic potential and also environment protection are being realized and will be realized only by high quality workers. Thus a program of transition to a more effective provision of activities with simultaneous increase in qualification and multipurpose use of laborforce is a part of the equipment development program.

Annex No.1, 2
inštalovaný výkon v SE-VET o.z. - Installed Capacity in SE-VET o.z.

Possibilities of Further Utilization of Hydroenergetic Potential of the Slovak Republic

Ladislav Tarbajovský

This entry deals with a description of possibilities of energetic utilization of so far not used sections of main streams, it does not cover possibilities of construction of hydroelectric power plants on border streams and less important streams in the eastern part of the Slovak Republic.

River Váh

Locations, description and problems of not used sections of the river Váh. Schemes of possible utilization of respective sections, their advantages and disadvantages.

It results from a comparison of possible and present utilization of the river Váh, that we still have about 42% of a not used potential available in its basin. About 5% of which is represented by VD (hydro power project) Žilina which is under construction at present. Remaining almost 37% is hidden in so far not utilized but sufficiently prospective sections of the river Váh at which this entry is aimed.

On a lower section of the river Váh from a watersmeet with the Danube, after building VD Kráľová, the energetic use is very complicated especially due to an uncertainty in existence of VD Nagymaros or a project which could replace it, respectively. This area is also threatened by efforts at an exclusive utilization of the river for navigation purposes.

A not used section representing about 170 GWh/year (5%) is above VD Kráľová up to VE (hydroelectric power plant) Madunice. Utilization of this section is in a phase of preparation of VD Sereď-Hlohovec, in which the main effect, except the electric energy production, will be water purposes including making the river navigable.

If we do not include VD Žilina, which is under construction, among not used sections, then next section with a possibility to gain about 150 GWh/year (4%) is the section from the end of a backwater of the reservoir Žilina up to VE Lipovec.

A section from the reservoir Krpeľany up to VE Bešeňová which represents about 166 GWh/year (5%) is a next one. This section can be used by a system of 17 low river stages.

The remaining part of a technically usable hydroenergetic potential (HEP) of the river Váh is related to other partial basins (the river Váh above Liptovksá Mara, the rivers Orava, Nitra, Kysuca, etc.). A schematic longitudinal profile of a proposal of utilization of HEP of the river Váh is shown in fig.1.

The River Váh Section between VD Kráľová and VE Madunice

Brief description of a present state of the area in question

The area in question is located in a fluvian plain of the river Váh stream limited by the towns Sereď and Hlohovec in a stream section between the river kilometers 76.0 and 101.9 (a mouth of a waste channel of VD Madunice), which represents 25.9 km of the original stream. From the hedroenergetic point of view, the VD Sereď-Hlohovec is limited by VD Madunice and VD Kráľová.

The whole stream section is protected against large waters with a dam on the right side. This dam uniquely determines the area of a right bank inundation. The left bank inundation is, except a short section below the town Hlohovec, bordered with slopes of Nitrianska pahorkatina. The inundation, except the forests, has an agricultural use.

The whole section of the stream, and also the inundations, are characterized by human activities, such as stream changes, gravel mining, agricultural production, etc. Both the human activities and a natural activity of the stream have signed themselves on slope deformations of

Nitrianska pahorkatina nearly in the whole section in question. Terrain altitude in a near vicinity varies from 122 to 140 meters above sea level (Bpv.).

Technical Design Concept

The basic conditions predetermining the concept of VD Sereď-Hlohovec are as follows:

- a gross head given by an *upper operational level of VD Kráľová (122 to 124 meters above sea level)* and the *required lower level of VD Madunice (141.10 meters above sea level).*
- shipping path of a required class E-21
- HEP utilization
- evaluation of an underground water mode
- evaluation of a soil fund bite
- territory protection against large waters
- minimalization of a building and technological work and also the site load due to construction
- evaluation of a recreation potential in the area

Two basic alternatives of the VD, i.e. derivative and river ones, are being evaluated from the point of view of environment protection at present.

Table 1.

Profile	Basin area km^2	Hydrologic conditions: Course of large waters						
		1	5	10	20	50	100	years
First class rod Sereď-Šintava	10,379	913	1,379	1,554	1,710	1,913	2,060	$m^3 s^{-1}$

* VD Sereď-Hlohovec - alternative 1

VD Sereď-Hlohovec (fig.2 - a derivative scheme) consists of the following **main objects:**

Siladice reservoir - starts *with an inflow into a supply channel and* **a Siladice weir** *and ends* **in a place of a mouth of a waste channel** *of VE Madunice into the* **river Váh. The reservoir is 10.02 km long. The reservoir is dammed on both sides with a crest at the elevation 142.60 meters above sea level Bpv.**

Fig.2. **A Proposal for Utilization of the River Váh Hydropotential (SEREĎ-HLOHOVEC section) the river kilometers 64.025 - 107.000.**

The main function of the Siladice reservoir is to ensure a present level in the town Hlohovec when large waters pass through, to create a volume to enable a tandem operation with VE Madunice and to enable fulfilling of all of the landscape shaping functions (fauna, flora, recreation, microclimate).

Different pieces of infrastructure (water pipeline, gas pipeline, crude oil pipeline) are led across the designed *reservoir* which must be taken into account during the construction.

Siladice weir - the weir profile is designed in a channel of the river Váh at the river kilometer 99.800. The weir will have five fields wide 16 m each or four fields wide 21 m each, *respectively. A dammed height is 9 m. A segment with a shutter is designed as a damming structure.*

A biocorridor is considered to be built in the right hand side abutement of the weir.

A regenerating flow in the amount of 7 $m^3.s^{-1}$ which will be used by a small hydroelectric power plant **(MVE) will be discharged into the original channel. Road access to the villages Vinohrady nad Váhom and Dvorníky from** the village Siladice will be provided by building a bridge across the weir and a tunnel below the supply channel.

The supply channel - total length of the supply channel is 5.4 km. A cross section consists of a modified trapezoid with a bottom width 45 m and a slope gradient 1:2 up to the elevation 140.60 m above sea level and 1:9 up to the elevation 141.60 m above sea level. The crest of dam is at the elevation 142.60 m above sea level. The water part of the dams in the section with the slope 1:9 will be changed as for the vegetation. A stabilizing part of the body will be changed by an additional fill of a varying shape enabling vegetation changes. In the places in which the morphology and stability of slopes of Nitrianska pahorkatina enable it, the route will approach so that the left hand side dam would be integrated with these slopes.

The channel bottom copies the actual terrain nearly along its entire length. A foil was designed as a sealing element for entire length of the channel, i.e. both the bottom and slopes.

Sereď hydraulic node - the hydraulic node was designed on the left bank of the river Váh at the kilometer 5.480 after considering the terrain configuration and slope deformations on Nitrianska pahorkatina. It consists of a VE and a gate (PK). The VE is located to the right into the PK and from a building point of view, it is designed for installation of two vertical Kaplan turbines with an absorption capacity 2 x 150 $m^3.s^{-1}$ and power output 2 x 23.59 MW. Assumed average yearly electricity production is 169 GWh. The gate is designed with parameters of E-21 class. Its utility ground plan dimensions are 24 x 110 m with a depth providing navigation of ships with a draught of 3.5 m.

Waste channel - this object hydraulically connects the hydraulic node of VD Sereď with a reservoir of VD Kráľová. The path of the channel was selected outside the original river channel with respect to abandon a slide area to the north of a village Šintava.

A combination of the channel with meanders of the original river channel creates conditions for suitable assembly of different communities of fauna and flora. The inundation area will be completed with a network of bridges (a road bridge, foot bridges and bridges for cyclists) and a port for sporting vessels for activation of the whole path of the waste channel as a recreation area for the town Sereď.

The length of the waste channel is 5,535 m.

The river Váh modifications in the section Siladice-Sereď - a function of the old river channel will be partially changed due to building the supply channel. At the time when flows in the river Váh are less than the absorption capacity of the hydroelectric power plant, a flow of 7 $m^3.s^{-1}$ will be additionally supplied into the old river channel. At the time of large flows, the old river channel must be able to safely pass them.

Rescue of slamps - rescue of slope deformations is urgent in the sections with active slamps also outside the scope of an actual preparation of VD Sereď.

* VD Sereď-Hlohovec - alternative 2

Alternative II (fig.3 - a river scheme) of VD Sereď covers a river variant with HEP utilization in three stages. This alternative, in the same was as the preceding one, is based on a tandem operation with VD Madunice. Absorption capacity of these plants is also 300 $m^3.s^{-1}$.

Arrangement of the stages is based on a requirement for reduction of a difference between the levels in a reservoir and below the stage related to the existing level mode and also on a requirement minimalization of surfaces of the reservoirs so that dammed levels did not run out of the original channel of the river Váh. Based on this criteria, the individual river stages were designed in the following profiles:
- river kilometer 80.550 - Dolný Čepeň
- river kilometer 90.200 - Zelenice

- river kilometer 96.600 - Šulekovo

Parameters, layout and also the technical design of the main building objects in all the stages are the same. Assumed yearly production of electric energy is 134.5 GWh in total.

Fig.3. A proposal for utilization of hydropotential of the river Váh (SEREĎ-HLOHOVEC section) the river kilometers 64.025-107.000 (status of preparation by 1996).

Possibilities of utilization of the section from VE Lipovec to VD Žilina

The section of the river Váh form VE Lipovec to the end of damming of a reservoir of VD Hričov is about 25 km long.

A mode of utilization of the section of the river Váh from the mouth of the river Varínka to the reservoir of VD Hričov was defined by starting the construction of VD Žilina in 1994. The remaining not used section of the river Váh from VE Lipovec to the end of a damming in the reservoir of VD Žilina is about 12 km long. A gross not used head between a lower level of VE Lipovec and the maximum level in the reservoir of VD Žilina is about 20.6 m.

The section can be used in several technical realistic schemes (schemes with PVE (pumped storage plant) Hoskora are not considered):

- with one large stage located below the railway bridges at the kilometer 264.25 (Strečno) according to the design from 1964 [1] or from 1985 [2] and from 1988 [3].
- with one large stage located above the railway bridges at the kilometer 266.05 (Starhrad) according to the design from 1985 [2] and 1988 [3].
- with one middle large stage located below the railway bridges at about the kilometer 264.95 (Nezbudská Lúčka) according to the design from 1992 [4].
- with two middle large stages according to the design from 1985 [2] and 1988 [3]. The first was located above the railway bridges at the kilometer 266.06 (Starhrad) and the other was located below the railway bridges at the kilometer 264.25 (Strečno).
- with two small stages according to the design from 1992 [4]. The first one was located in Domašiansky meander at the kilometer 267.50 and the other below the railway bridges at the kilometer 264.95.

Based on the evaluation of geologic conditions and especially an ecological evaluation of the site [5], two variants of energetic utilization of this section [6] were proposed in 1995 (tab.2).

* Variant 1 - utilization of the section with one stage (fig.4).

The Nezbudská Lúčka is located at the kilometer 264.95, i.e. 790 m below the lower railway bridge. The upper level is considered to be at the elevation 364.00 meters above sea level. A weir with three fields wide 16.5 m each is located in a tapping on the right side of the river Váh channel. VE with two direct-flow Kaplan turbines with an absorption capacity 110 $m^3.s^{-1}$ each is designed on the left side of the weir. A water damming created above the stage reaches as far as the beginning of Domašiansky meander, i.e. into a distance of about 4,500 m. On the right side of the flow, the level is directed into the original channel of the river Váh by means of a protective dam about 1,500 m long, which follows up with the right inflow wing of the weir. On the left side of the river channel, there is a permanent overflowing of a part of the area between the road and the left bank in the lower half of the Domašinsky meander. Deepening of the river channel by 1.5 m to the elevation 353.00 meters above sea level is considered below the stage. The deepening is about 1,200 m long. A road bridge is being built across the weir and the VE to connect both the banks. A water biocorridor about 1,550 m long is designed along the right side of the VE.

Fig.4. A proposal for utilization of hydropotential of the river Váh (HRIČOV-LIPOVEC section) the river kilometers 245.60-278.46 (status of preparation by 1996).

* Variant 2 - utilization of the section with two stages (fig.5).

The first stage Starhrad is located at the kilometer 266.02, i.e. 200 m above the upper railway bridge. The upper level is considered to be at the elevation 367.00 meters above sea level. A weir with four fields wide 16.5 m each is located on the right side of the river Váh channel. VE with two direct-flow Kaplan turbines with an absorption capacity 110 $m^3.s^{-1}$ each is designed on the left side of the weir. A water damming created above the stage reaches as far as the kilometer 270.5 of the length measurement of the river Váh, i.e. to a distance of about 4,500 m. On the right side of the flow, the level is directed into the original channel of the river Váh by means of a protective dam about 500 m long which follows up with the right inflow wing of the weir. On the left side of the channel there is a permanent overflowing of a part of the area between the road and the left bank along the entire length of the Damašínsky meander.

The second stage Nezbudská Lúčka is located at the kilometer 264.95. basic description of this stage is the same as that one in the variant 1 provided that the level in the reservoir is designed at the elevation 361.00 meters above sea level. A water biocorridor is designed on both the sides of the VD.

Tab.2.

Basic energetic parameters of VE

Parameter		Variant 1	Variant 2	
		Nezb.Lúčka	Starhrad	Nezb.Lúčka
Absorption capacity	$m^3.s^{-1}$	220	220	220
Max. net head	m	9.24	5.8	6.37
Installed capacity	MW	18.6	11.0	13.0
Available capacity	MW	17.4	10.9	12.0
Average yearly production	GWh	54.8	34.0	37.9

Fig.5. A proposal for utilization of hydropotential of the river Váh (HRIČOV-LIPOVEC section) the river kilometers 245.60-278.46 (status of preparation by 1996).

* Mode of operation of VE

The hydraulic mode of the designed VEs is affected by a yearly mode of accumulating reservoirs Liptovská Mara and Orava and a daily mode of the reservoir Krpeľany. The designed VEs do not have reservoirs designed for daily control of flows. With respect to increased requirements for environment protection, a flow mode of VE with a constant level was considered.

A daily mode of flows in a profile of the designed VE is a variable daily mode of the cascade of VEs Krpeľany-Sučany-Lipovec and a steady one corresponding to lateral water inflows from a basin between the weir in Krpeľany and the profile of VE.

Energetic Utilization of the River Váh between Bešeňová and Krpeľany.

The section between the existing VDs Bešeňová and Krpeľany (upper Váh III) in a total length about 35 km with a gross head of about 85 m provides a yearly production of electric energy of about 166 GWh. Energetic utilization of this section of the river Váh has been studied since 70s and the following three basic variants have been evaluated:

1. Left hand side derivation considered to guide water from the river Váh through a left hand side tunnel. Output was considered in the reservoir Nolčovo. This basic scheme also covered possibilities of building PVE with large accumulating reservoirs Vlkolínec and Ľubochňa.

2. Right hand side derivation considered to guide water from the river Váh through a tunnel in the right hand side rock block into a basin of the river Orava.
3. *A system of eight river stages with a relative height (7 to 13 m) and a total absorption capacity* 160 to 200 $m^3.s^{-1}$ (peak-load VEs).

At the end of 80s, opinions on an energetic utilization of this section of the river Váh stabilized on river stages with substantially lower heads which meant a larger number of stages in its utilization. In 1991, also the height of stages was finally stabilized on about 5 m by preparation of a proposal for a typified stage [7].

Site characteristics

The section of the river Váh between VDs Krpeľany and Bešeňová is along the whole length limited by a first class road I/18 Žilina-Poprad on one side and by the main east-west railroad (Košice-Žilina) on the other side. This specific location of both the main communication paths bordering the river Váh stream in a relatively narrow vicinity in combination with residential and industrial built-up areas in an immediate vicinity of the river Váh required regulation changes in the river Váh. These changes started at the end of the last century, left hand side bank slope modifications in a cadastral territory of the village Rojkov in a length of 260 m in 1899. At present, a section of a total length 11,837 m out of the total length of about 35 km, i.e. about 34% of the length, is regulated on one side or both sides, respectively. More over, a total amount of 1,974 m of protecting earth dams max. 3 m high is built in the area of Ružomberok. 9 bridges and footbridges in total were required to be built across the river Váh in construction of a communication network.

Hydrologic documentation

Flows according to a twenty year operation of the Bešeňová reservoir were evaluated for a design of individual stages and based on a previous optimalization, a proposed absorption capacity Q_n of MVE in the following three sections is considered:
- section I - the river Váh above Revúca $Q_n = 40\ m^3.s^{-1}$
- section II - the river Váh above Orava $Q_n = 60\ m^3.s^{-1}$
- section III - the river Váh at Kraľovany profile $Q_n = 90\ m^3.s^{-1}$

A concept of a technical design:

A proposal for energetic utilization of the section of the river Váh in question is based on the following rules:
1. The existing character of the flows affected by the balanced reservoir Bešeňová will not be changed thus a flow character of the stage is considered.
2. Leveling of the levels of individual stages will be designed so that a not required damming of levels would occur at increased flows.
3. If required, the channel will be deepened so that the underground water level would not be reduced excessively whereas the normal operation of MVE will create stabilized levels with a minimum fluctuation.

Tab.3.

List of basic data on individual stages.

Stage	Capacity (MW)	Production (GWh/year)	Average flow
Kraľovany	3.30	26.48	79.4
Rojkov	2.37	12.91	42.6
Stankovany	1.78	9.76	42.6
Ľubochňa	1.53	8.10	40.2
Hubová	1.53	8.19	40.0

Švošov I	1.62	8.50	40.0
Švošov II	1.62	8.44	38.8
Hrboltová	2.05	10.53	39.6
Černová	2.25	11.72	39.3
Rybárpole	1.66	9.09	38.9
Ružomberok	1.16	7.38	32.4
Lisková I	1.20	7.24	31.6
Lisková II	1.22	6.89	31.4
Ivachnová I	2.08	10.38	31.0
Ivachnová II	1.16	6.37	30.8
Ivachnová III	1.14	6.29	30.8
Lipt.Teplá	1.46	7.67	30.1
In total	29.13	165.94	-

4. The present state will not become worse due to flows of flood levels through individual stages.
5. Profiles of individual stages will be designed in the locations in which a building site can be developed.
6. Biting the land except the land belonging to Povodie Váhu will be minimized.
7. Profiles of individual stages will be located so that interests of environment protection would be injured minimally.
8. Zones of protective bank vegetation covers will be designed as a replacement for partial liquidation of bank covers and they will be suitably completed with traced fishways to preserve possible migration of fish.
9. The level will not be dammed excessively close to residential built up areas of villages extending directly to the river banks.

Stage location design

According to the character of the area through which the river Váh runs, the section in question can be divided from the point of view of location of the stages as follows:

- a section of Liptov basin, location of the stages - Lipt.Teplá stage, Ivachnová III stage, Ivachnová II stage, Ivachnová I stage and Lisková II stage
- the section of an intravilane of the town Ružomberok: location of the stages - Liesková I stage, Ružomberok stage, Rybárpole stage and Černová stage.
- the section of the river Váh below Ružomberok up to a riversmeet with the river Orava: location of the stages - Hrboltová stage, Švošov II stage, Švošov I stage, Hubová stage, Ľubochňa stage, Stankovany stage and Rojkov stage.
- the section below the riversmeet with the river Orava: location of Kraľovany stage.

The schemes of the stages are shown in fig.6 and 7 and a list of basic data of the stages is shown in tab.1.

Absorption capacities of MVEs

Absorption capacity of turbines was derived from the absorption capacity of the turbines in MVE Bešeňová taking into account the side water inflows especially of the rivers Revúca and Ľubochnianka. In considerations about operation of MVE in this section of the river Váh, it should be realized that VE Bešeňová which is controlled by PD VET will be the governing VE of this group of MVEs (without taking into account their number). Its operation is affected by the functions of VD Bešeňová as a "balancing" VD for PVE L. Mara and VDs through which the flows at VEs of the Váh cascade are affected from the reservoir L. Mara.

Environmental evaluation

The first work of an environmental character was carried out in this section in 1991 and 1992 which considers this designed system of MVEs as a unit, especially from the point of view of an ecology, as non-acceptable, but it also states that the unfavorable effects mentioned above do not have to occur in a successive, ecologically conditioned construction of several selected stages.

The stages were divided into the following four categories:
- suitable for realization: 1 stage
- conditionally suitable for realization: 8 stages
- conditionally suitable - troublesome: 4 stages
- unsuitable at present conditions: 4 stages

Relationship with a railway line

Nearly the whole area of the upper river Váh III in question is in an immediate contact with a railway line of the main railway line Čierna nad Tisou-Žilina. A possibility of construction of *a new railway line (for a higher speed) even after construction of MVE was proved when reevaluating* the design of co-existence of modernization of ŽSR network and the prepared MVEs.

Power output from MVE

Possibilities for output of the power from MVE in the section of the river Váh III were studied separately. Local 22 kV and 110 kV lines are available for power output.

Possibilities of connection of MVE into a distribution network were analyzed provided that all MVEs exist in this section, i.e. somehow a final state.

Analysis of the problem of power output from MVEs built in this region pointed out to a need of a close cooperation between the operators of MVEs and a distribution company to which demanding situations from the point of view of operation arise due to connection of MVEs (even one by one) which can affect economic relations when selling energy from these sources.

River Hron

The river Hron, in its length of a stream 240 km with a gross hydraulic head 400 m, offers 761 GWh/year of technically usable hydroenergetic potential. Respecting the environment protection requirements, stated in a law on environment protection, these parameters cannot be taken into account. That was the reason why designs of energetic utilization of the river acceptable from the point of view of environment protection were prepared at present.

Site characteristics.
Hydrologic conditions.

The river Hron, in the section between Kozárovce and Tlmače, runs through so called Slovak gate *between volcanic spurs of Štiavnické vrchy and Kozmálovské vŕšky. The river Hron runs* into a wide alluvial flat with a meandering channel behind this section. High banks are eroded in concave sections and material deposits occur in convex sections. In this section, the Hron channel is 50-60 m wide at the bottom and has a capacity up to a bank line Q_1 - Q_{3r}. At larger flows, water runs out of the banks and floods the left bank area between the river Hron and the channel Perec. The right *bank is located higher. Large waters culminate above* Levice, *then they decrease as far as the mouth* due to insufficient inflows. The largest flows are in spring and the lowest ones are in autumn in a long term average. Veľké Kozárovce and Môťová reservoirs are built in the river basin and construction of Slatinka water reservoir is being prepared. The reservoirs will provide a water supply for the main consumers JE (nuclear power plant) Mochovce and irrigation.

Flow characteristics of the river Horn in Kálna profile.

Average daily flows Q ($M^3.s^{-1}$) exceeded N-days in a year.

30	90	180	270	330	355	364 days
121.70	61.05	33.55	22.52	15.48	12.38	9.27 Q

Flows Q ($m^3.s^{-1}$) repeated once in N-years.

1	5	10	20	50	100	years
310	520	600	675	760	950	Q

Underground water mode.

It is heavily affected by a relationship among geomorphologic conditions, geologic structure, hydrology of the river Hron, precipitation and human activities. General direction of flow is identical with the direction of a stream flow. Drainage effect of the river Hron is negligible.

The original natural mode was heavily affected by extensive changes in the stream, construction of drainage channels, pumping form the wells and construction of hydro power projects.

Changes in the channel and gravel mining exceeding water transportation of bottom scours caused a river erosion which results in deepening of the river channel.

The hydro power project Kozmálovce divided the river into two independent sections, however having a different character as for the natural environment. This was also the way how their design was approached to.

Lower section.
Veľké Kozárovce - mouth.

Original designs of a continuous utilization of the river Hron joined several important technical and economic interests: protection of an agricultural land fund against floods, protection of intravilans, gravel mining from the river Hron, water consumption for industry, etc. These interests are more or less colliding with environment protection and that was why neither power engineers considered a continuous utilization of the lower section of the river Hron.

However, acute lack of available water for the countryside in the surroundings of the river is a key problem at present. Growing drought and level decrease in the river Hron due to changes of the river channel causes depletion and fading away of about 1,000 hectares of meadow florists, depletion of abandoned branches cut from the river which has a character of a super regional boicorridor and is a backbone of ecological stability of the Levice region.

With respect to the fact mentioned above, the technical changes are required which are aimed at the following:
- to locally raise the river levels and neighboring underground water
- to enable seasonal run of the water from the river Hron out of the banks
- to make the dry branches flowable
- however, to minimize consequential negatives during these changes, such as minimalization of damming, construction of biologically acceptable fishways, etc.

After several unsuccessful attempts to design and realize such goals without an energetical use, the sections which would meet both the ecological and energetic requirements were selected in cooperation of a team of ecologists and technicians directly in the countryside. A combination of interests of ecology and power engineering is the only real way at present to save an ecosystem of the lower river Hron. However, these investments will be provided nearly below the level of economic acceptability without an appreciation of the ecological benefits.

Based on these ecological rules mentioned above, the first most complicated sections were selected which will be designed by construction of river stages with an energetic utilization Vozokany, Šárovce, Turá, Marušová, Nový Tekov.

To meet the ecological requirements during the preparation of the construction of water stages will be possible only at a price of a technically more demanding design. Thus first of all, it will be necessary to measure the actual bottom as for the height, washed banks of the main channel, in the profiles of inflows and outflows of branches and bottoms of the branches specified for making them flowable. Then it will be possible to define an upper level and thus also the heads in individual stages.

The lower stages Kamenica and Kamenín are a special case. The lowest stage Kamenica can be built only in the case if the VD Nagymaros is not built.

The Kamenín stage the main function of which is a water function - water supply for irrigation in a lower river Hron, will be built in cooperation with a water management investor.

According to the materials available so far, the parameters of the stages were specified as is shown in a table.

Table of parameters for respective stages.

Item	Stage name	Average rate of flow	Max. head	Absorption capacity of turbines	Installed capacity	Average yearly production
		$m^3.s^{-1}$	m	$m^3.s^{-1}$	MW	GWh
1	Kamenica	55.1	6.1	60.0	2.71	12.44
2	Kamenín	54.7	5.1	60.0	2.15	9.20
3	Vozokany	52.7	4.9	60.0	1.74	8.68
4	Šárovce	52.0	3.5	51.0	1.09	5.88
5	Turá	52.0	4.2	60.0	1.49	7.43
6	Marušová	51.6	4.3	54.0	1.32	7.07
7	N.Tekov	51.6	4.0	54.0	1.29	6.91
8	V.Kozmálovce	51.4	7.7	84.0	5.23	14.50

Upper section: Veľké Kozárovce - Brezno

In a similar way as on the lower section of the river Hron, the possibilities of realization of river stages with MVEs and their locations were studied so that they meet certain water, ecological and technical parameters provided that the negative effects on environment are minimized. It was proved that the concepts of utilization of the river Hron with large reservoirs (Hliník, Ladomer, Hronská Dúbrava, etc.) designed so far are difficult to realize due to a large impact on environment. In the described proposal of a concept of MVEs, the goal was to make use of a natural hydropotential of the river Hron in an acceptable extent. In this section, the needs to solve ecological problems of the area act in a lower extent, on the other hand it should be protected even if due to continuous modifications of the river channel, e.g. in the areas of Žiar nad Hronom, Vlkanová and Zvolen, the natural river channel has been destroyed.

Hydrologic conditions.

The whole section of the river Hron from Brezno to Zvolen has a natural hydrologic mode. It is slightly affected by Hriňová and Môťová reservoirs below the town of Zvolen and it can also be substantially affected by Slatinka reservoir in future. These reservoirs have only an insignificant positive influence for the system of MVEs.

Normal flows of the river Hron run through a cuvette of the river channel. Larger flows run out of the banks and thus the stream is limited with dams in some sections.

Flow characteristics of the river Hron in Banská Bystrica profile.

Average daily flows Q ($m^3.s^{-1}$) exceeded N-days in a year.

N	33	90	180	270	355	364
Q	62.0	35.0	19.6	12.2	7.55	5.88

Flows Q ($m^3.s^{-1}$) repeated once in N-years.

n	1	5	10	20	50	100
Q	155	260	310	360	400	430

Technical design of the stages.

Head and flow conditions in this section are similar in individual profiles. Thus it is possible to repeat the technical design of the stages which is preferable from the economic point of view.

A stage consists of a machine room of MVE, located near the closer dam as a rule, a damming object - a weir with a mobile damming structure. The weirs will be by-passed if water runs out of the banks. The MVE machine room is protected with an upper structure at greater flows and is accessible from the air side of the dam. A concrete pillar with a gravel gate is between the weir and MVE. A fishway in a form of a short bioby-pass will be designed round the stage on the left side of the weir in an inundation which can also be used for boating.

Heads in the stages vary from 2.5 to 5.0 m, thus the direct flow Kaplan turbines with a horizontal axis providing a minimalization of the building part of MVE are designed in the machine rooms of MVEs. Three or four machines are installed in MVEs according to the flow conditions. The turbines will drive asynchronous generators. MVE power output will be led into 22 kV public distribution network.

A final proposal of the concept of water energy utilization which can be considered as a balance of the interests of water management, power engineering and environment protection is shown in the following table.

Table of parameters for respective stages.

Item	Stage name	Average flow	Max. head	Turbine absorption capacity	Installed capacity	Average yearly production
		$m^3.s^{-1}$	m	$m^3.s^{-1}$	MW	GWh
1	Psiare	51.52	4.15	78.0	1.385	7.875
2	Okrut	49.97	4.20	76.0	1.270	7.286
3	Žiar nad Hronom	43.56	5.00	54.0	1.530	8.251
4	Šášovské Podhradie	41.64	4.30	54.0	1.290	6.779
5	Jalná	40.46	3.90	52.5	1.110	5.830
6	Hronská Dúbrava	39.43	4.10	54.0	1.250	6.323
7	Hronská Brezina	39.43	4.00	52.5	1.130	5.844
8	Budča	38.14	3.90	52.5	1.120	5.683
9	Zvolen I	30.57	5.30	45.0	1.335	6.724
10	Hájniky	30.07	4.40	39.0	1.000	5.023
11	Vlkanová	28.82	4.40	40.5	1.060	5.265
12	Iliáš	27.99	4.90	39.0	1.135	5.669
13	Šalková	23.47	3.70	25.8	0.555	3.149
14	Brusno	22.42	3.60	24.9	0.515	2.937

River Orava

The River Orava in the Section Tvrdošín - Krpelany

The concept of utilization of hydroenergy in the section in question is affected by preceding designs respecting the environment problems identified so far.

Total not used section of the river Orava is 57.915 km long in which the river creates a head of 137.7 m. The length of 24.6 km out of this section with a used head 70.2 m is covered in the study. So the utilization of hydropotential is about 50%.

The river section, according to the design, is divided into 12 river stages with a gross hydraulic head from 4.45 to 8.00 m.

The flows output from VD Tvrdošín according to manipulation instructions were used for design of absorption capacities of respective stages of MVE.

According to this, optimum absorption capacities from 5.0 to 65.0 $m^3.s^{-1}$ were specified.

Profiles of respective river stages were located into places in which the minimum impacts or damages, respectively could be caused from the point of view of environment protection. Protected areas were also taken into account in selection of the locations.

Technical designs of respective stages and their layout result from technologic equipment. A building part consists of VE close to a weir, a mobile weir, a fishway, modification of a river channel below the stage and respective related buildings. VE technology consists of tube turbines with a perpendicular transmission to an asynchronous generator. Three machines are installed in each stage. Technologic design is proposed in variant designs.

Electrotechnical equipment is located in VE and consists of synchronous generators with accessories.

Power output from the hydroelectric power plants is led into the existing ordinary 22kV lines.

Operation of the plants is supposed to be fully automatic, controlled according to the upper water level.

Total electric energy production in 12 stages is expected in an average year 107,578.5 MWh.

Basic technic parameters of the studied concept.

Item	Location	Head m	Absorption capacity m³/s	Capacity MW	Production GWh/year
1	Nižná	4.9	3x21.6	2.67	7.7
2	Krivá I	4.8	3x21.6	2.67	8.3
3	Krivá II	6.24	3x21.6	3.30	11.8
4	Dlhá n O.	4.75	3x21.6	2.67	8.4
5	S.Dubová	6.26	3x21.6	3.30	11.4
6	H. Lehota	4.26	3x21.6	2.67	7.8
7	Medzibrodie	5.86	3x21.6	3.30	11.1
8	Kňažia	5.06	3x21.6	2.67	9.8
9	Záskalie	4.16	3x21.6	2.67	8.0
10	V. Bysterec	4.06	3x21.6	2.67	7.9
11	Istebné	3.40	3x21.6	2.12	6.7
12	Žaškov	4.10	3x21.6	2.67	8.6
	-	57.85	-	33.38	107.5

Description of a Design Reduced due to a More Detailed Environmental Analysis

Žaškov, Kňažia, Nižná, V.Bysterec and Záskalie profiles in the evaluated concept were identified as acceptable ones for energy utilization. A gross hydraulic head up to 5.0 m recommended for all of the stages according to the materials known so far provided that the head will be created by damming the water level above the stage and deepening of the river channel below the stage.

The actual technical design of the stages will be adopted to environmental requirements especially in a building part.

The reduction of energetic utilization can be characterized as a substantial one with the following parameters:

Out of the total not used section of the river in the length 57.915 km, only 10 km will be used energetically and out of a total head 137.7 m, only 21.38 m will be used.

Then, total production in these stages in an average year will be 40,643 MWh.

Basic technic data of the reduced concept.

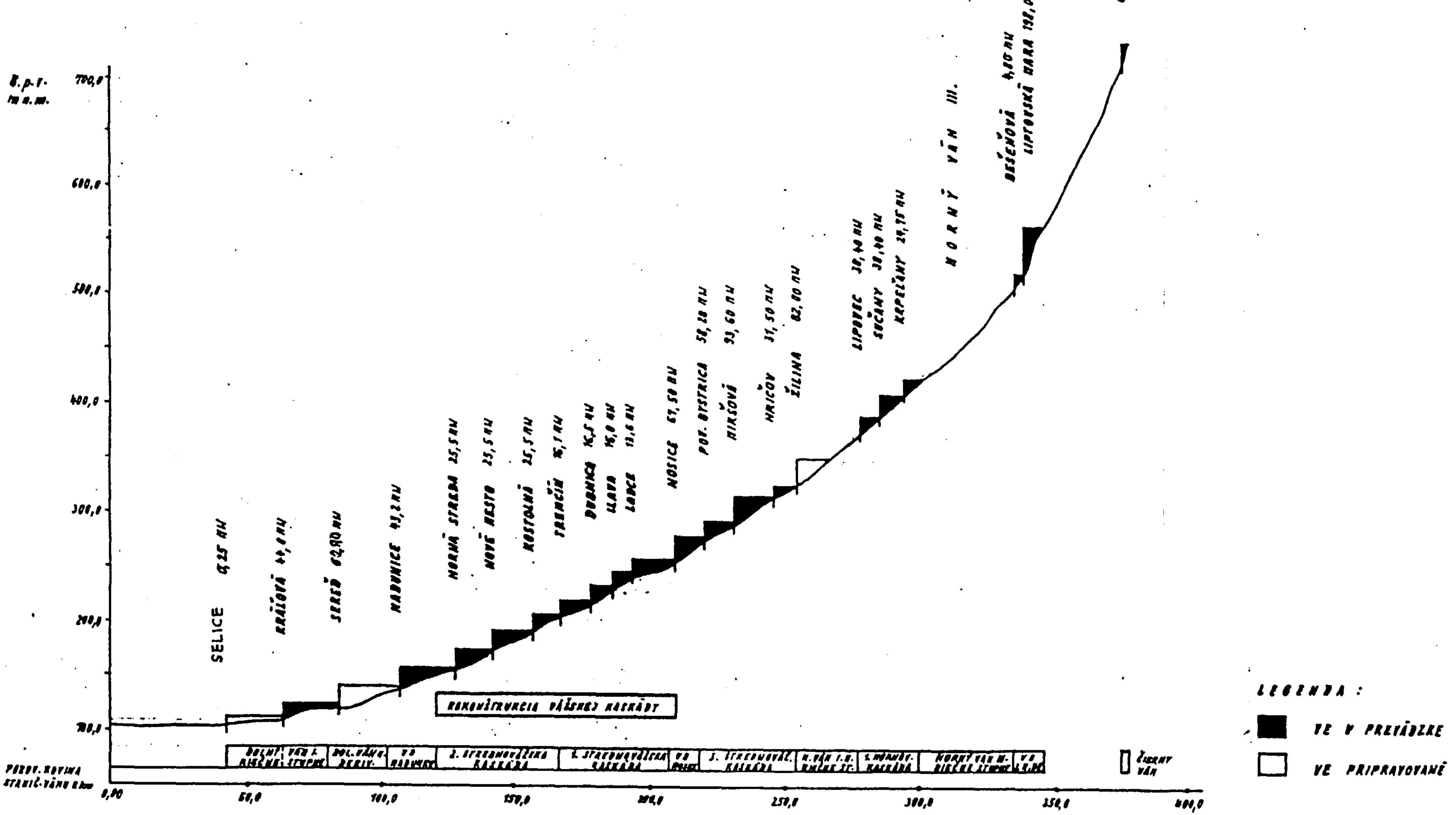
Item	Location	Head m	Absorption capacity m^3/s	Capacity MW	Production MWh/year
1	Nižná	4.0	65	2.4	6,307
2	Kňažia	5.06	65	2.9	9,805
3	Záskalie	4.16	65	2.5	8,601
4	V. Bysterec	4.06	65	2.4	7,872
5	Žaškov	4.10	65	2.4	8,058
	Total	21.38		12.6	43,643

Conclusion

Extensive experience in hydropotential utilization, steadily growing electricity consumption despite of realization of saving measures and absolute lack of other energy resources predefine utilization of our rivers for its production just from these natural resources. Permanent contact with a nature protection and environmental approach when designing the final appearance of hydro power projects ensures minimalization of impacts on a natural environment.

obr. 1

Návrh využitia hydropotenciálu rieky Váh



SF a.s., VET o.z.

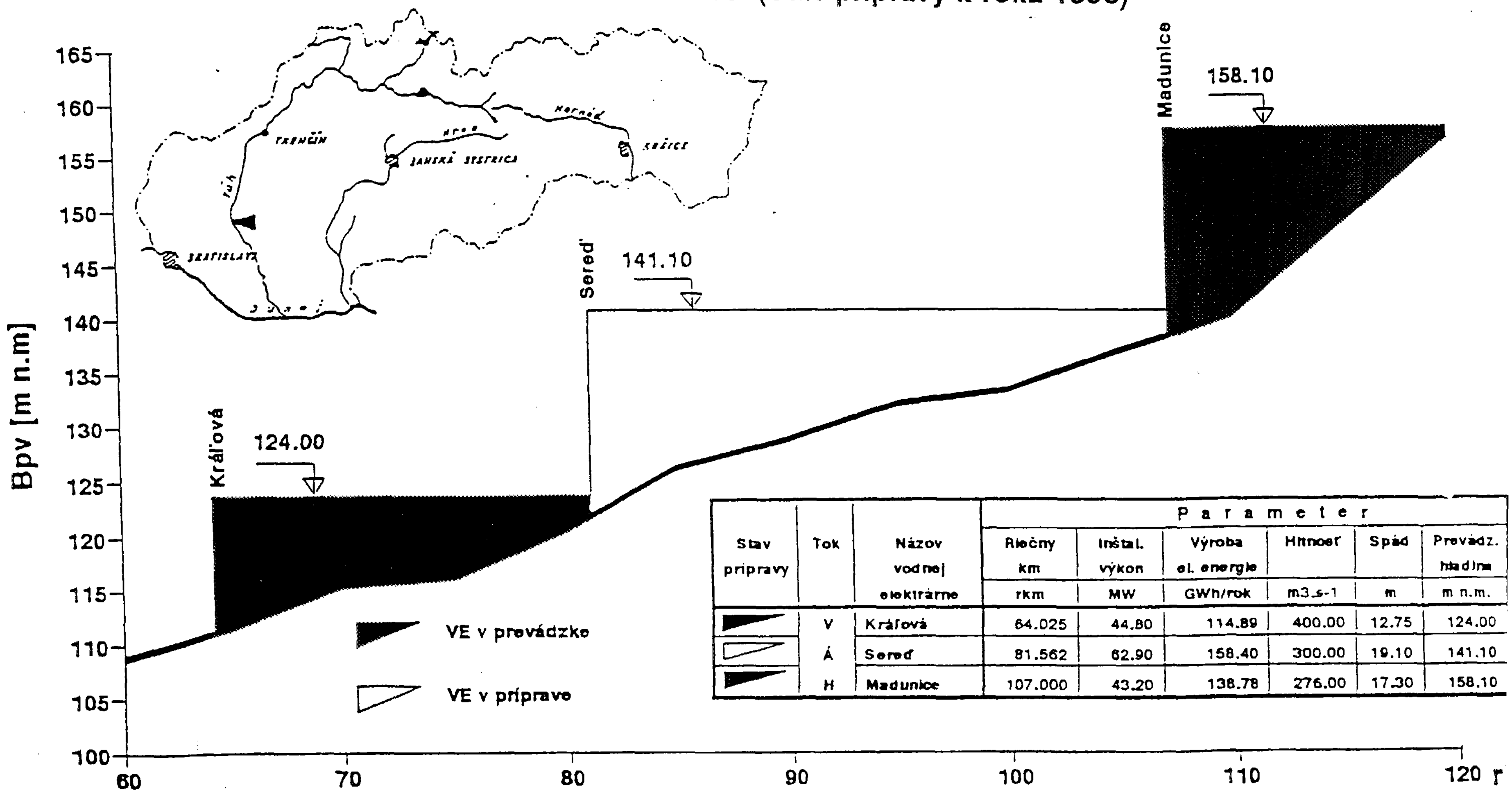
Obr.1 (Fig.1)

A Proposal for Utilization of Hydropotential of the River Váh

B.p.v. m n.m. - B.p.v. m a.s.l.
porov.rovina stanič.Vahu R km - comparing level of length measurement of the river Váh R km
hroný Váh III - upper Váh III
rekonštrukcia vážskej kaskády - Váh cascade reconstruction
dolný Váh I, riečne stupne - lower Váh I, river stages
dol. Váh deriv. - lower Váh, deriv.
2.strednovážska kaskáda - middle Váh cascade 2
1.strednovážska kaskáda - middle Váh cascade 1
3.strednovážska kaskáda - middle Váh cascade 3
h.Váh I.II, riečne st. - upper Váh I.II, river stages
1.hornov.kaskáda - upper Váh cascade 1
horný Váh III, riečne stupne - upper Váh III, river stages

Legend:
VE v prevádzke - VE in operation
VE pripravované - VE under preparartion

Návrh využitia hydropotenciálu
rieky Váh (úsek SEREĎ - HLOHOVEC)
v rkm 64.025 - 107.000 (Stav prípravy k roku 1996)



Stav pripravy	Tok	Názov vodnej elektrárne	Parameter					
			Riečny km	Inštal. výkon	Výroba el. energie	Hltnosť	Spád	Prevádz. hladina
			rkm	MW	GWh/rok	m3.s-1	m	m n.m.
	V	Kráľová	64.025	44.80	114.89	400.00	12.75	124.00
	Á	Sereď	81.562	62.90	158.40	300.00	19.10	141.10
	H	Madunice	107.000	43.20	138.78	276.00	17.30	158.10

Obr.2 (Fig.2)

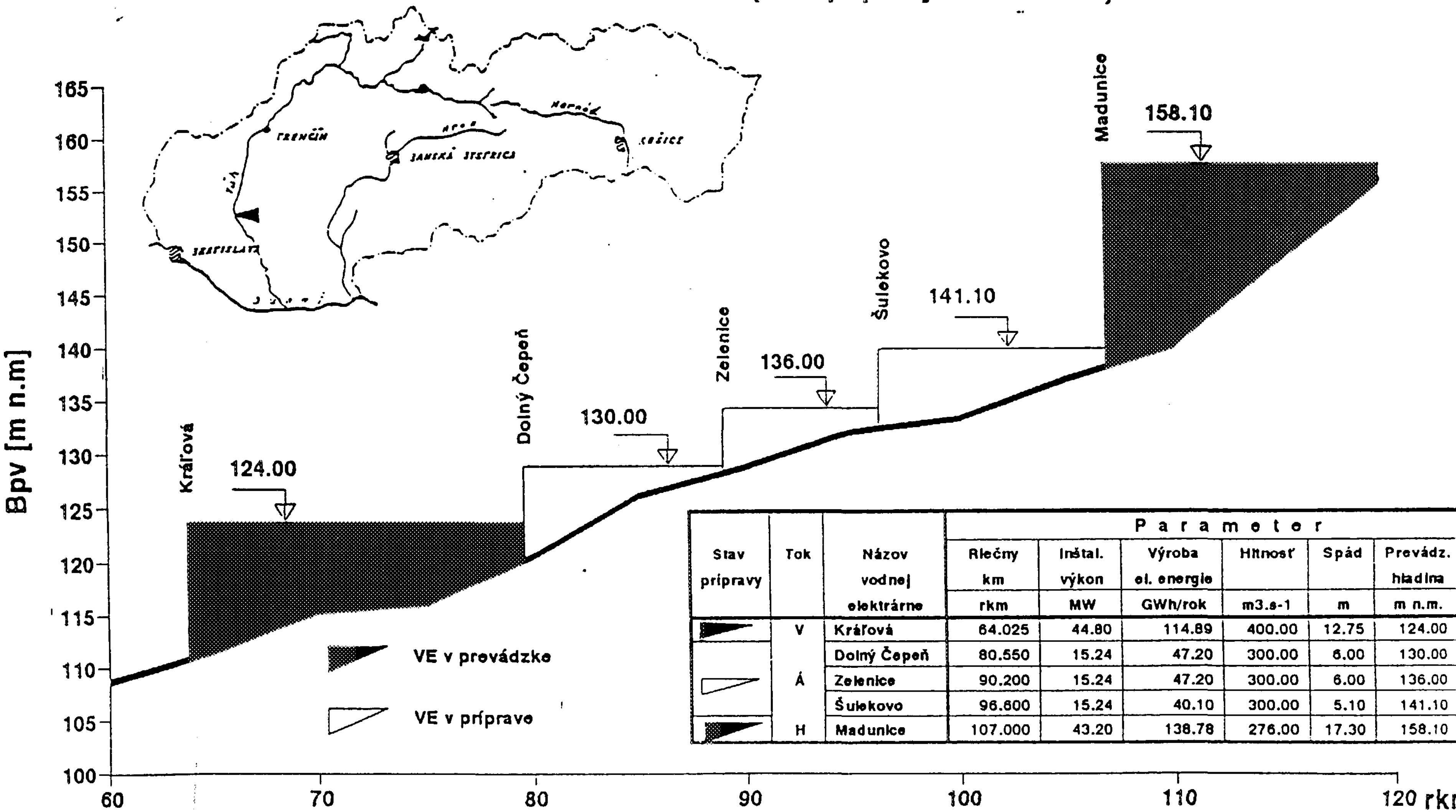
A Proposal for Utilization of the River Váh Hydropotential (SEREĎ-HLOHOVEC section) the River Kilometers 64.025 - 107.000.

VE v prevádzke - VE in operation
VE v príprave - VE under preparartion

stav prípravy - preparation status
tok - stream
názov vodnej elektrárne - hydroelectric power plant name
parameter - parameter
riečny km - river km
inštal. výkon - installed capacity
výroba el. energie - electricity production
hltnosť - absorption capacity
spad - head
prevádzková hladina - operational level

obr. 3

Návrh využitia hydropotenciálu
rieky Váh (úsek SEREĎ - HLOHOVEC)
v rkm 64.025 - 107.000 (Stav prípravy k roku 1996)



Stav prípravy	Tok	Názov vodnej elektrárne	Riečny km rkm	Inštal. výkon MW	Výroba el. energie GWh/rok	Hltnosť m3.s-1	Spád m	Prevádz. hladina m n.m.
VE v prevádzke	V	Kráľová	64.025	44.80	114.89	400.00	12.75	124.00
VE v príprave		Dolný Čepeň	80.550	15.24	47.20	300.00	6.00	130.00
	Á	Zelenice	90.200	15.24	47.20	300.00	6.00	136.00
		Šulekovo	96.600	15.24	40.10	300.00	5.10	141.10
VE v prevádzke	H	Madunice	107.000	43.20	138.78	276.00	17.30	158.10

Obr.3 (Fig.3)

A Proposal for Utilization of Hydropotential of the River Váh (SEREĎ-HLOHOVEC section) the River Kilometers 64.025-107.000 (status of preparation by 1996).

VE v prevádzke - VE in operation

VE v príprave - VE under preparartion

stav prípravy - preparation status

tok - stream

názov vodnej elektrárne - hydroelectric power plant name

parameter - parameter

riečny km - river km

inštal. výkon - installed capacity

výroba el. energie - electricity production

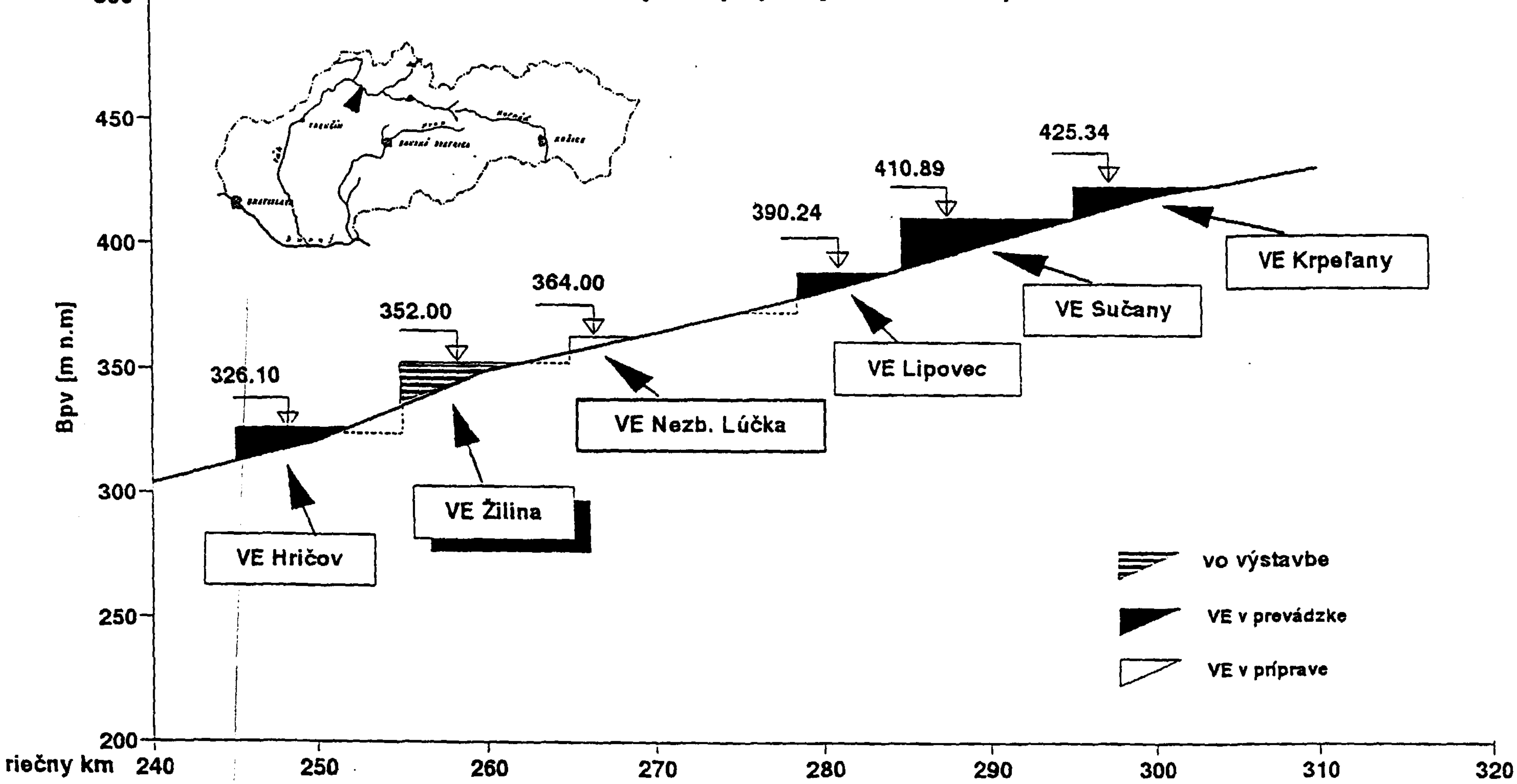
hltnosť - absorption capacity

spád - head

prevadzková hladina - operational level

obr. 4

Návrh využitia hydropotenciálu
rieky Váh (úsek HRIČOV - LIPOVEC)
v rkm 245.60 - 278.46 (Stav prípravy k roku 1996)



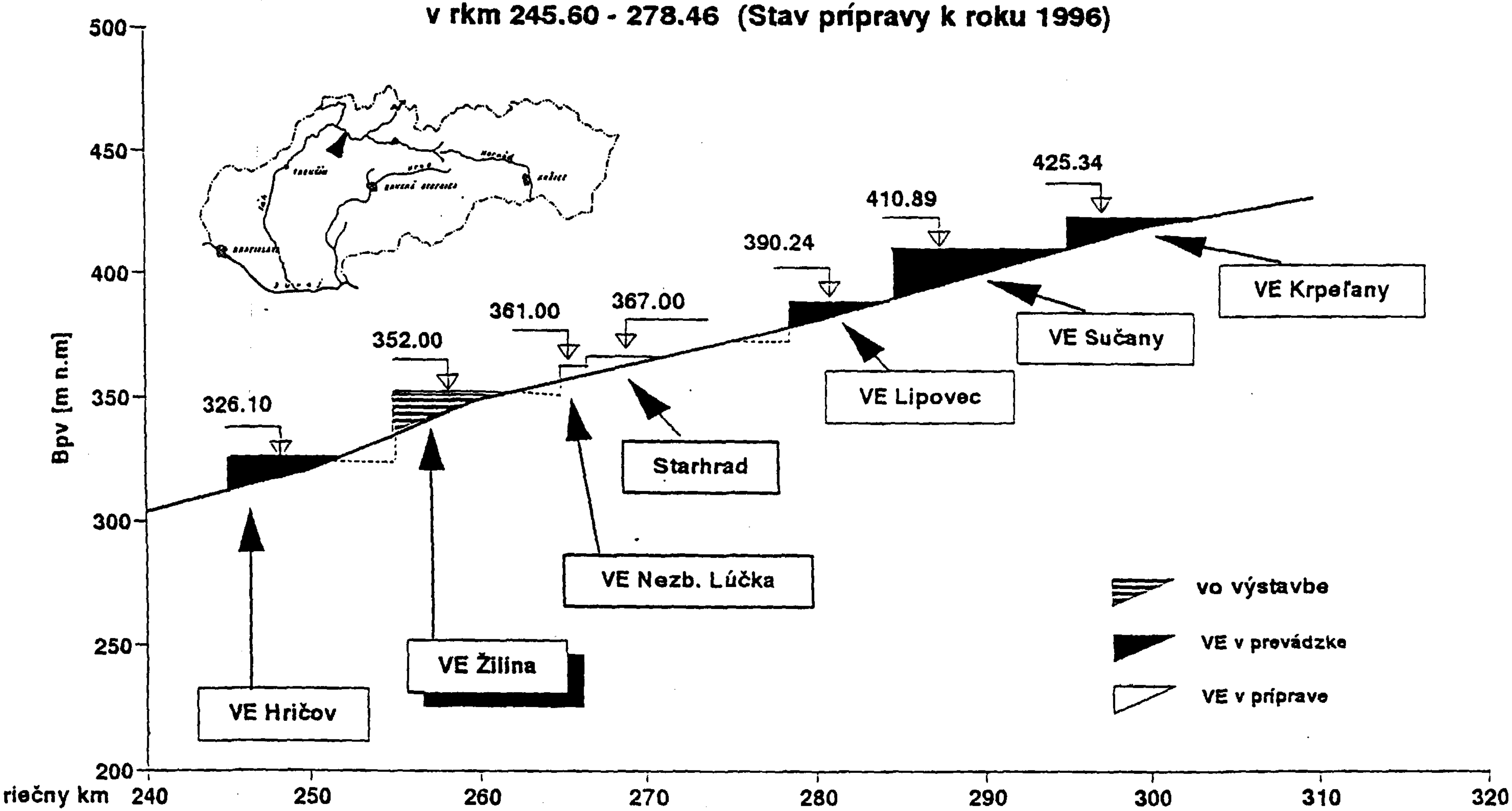
Obr.4 (Fig.4)

A Proposal for Utilization of Hydropotential of the River Váh (HRIČOV-LIPOVEC section) the River Kilometers 245.60-278.46 (status of preparation by 1996).

riečny km - river km
vo výstavbe - under construction
VE v prevádzke - VE in operation
VE v príprave - VE under preparartion

obr. 5

Návrh využitia hydropotenciálu
rieky Váh (úsek HRIČOV - LIPOVEC)
v rkm 245.60 - 278.46 (Stav prípravy k roku 1996)



Obr.5 (Fig.5)

A Proposal for Utilization of Hydropotential of the River Váh (HRIČOV-LIPOVEC section) the River Kilometers 245.60-278.46 (status of preparation by 1996).

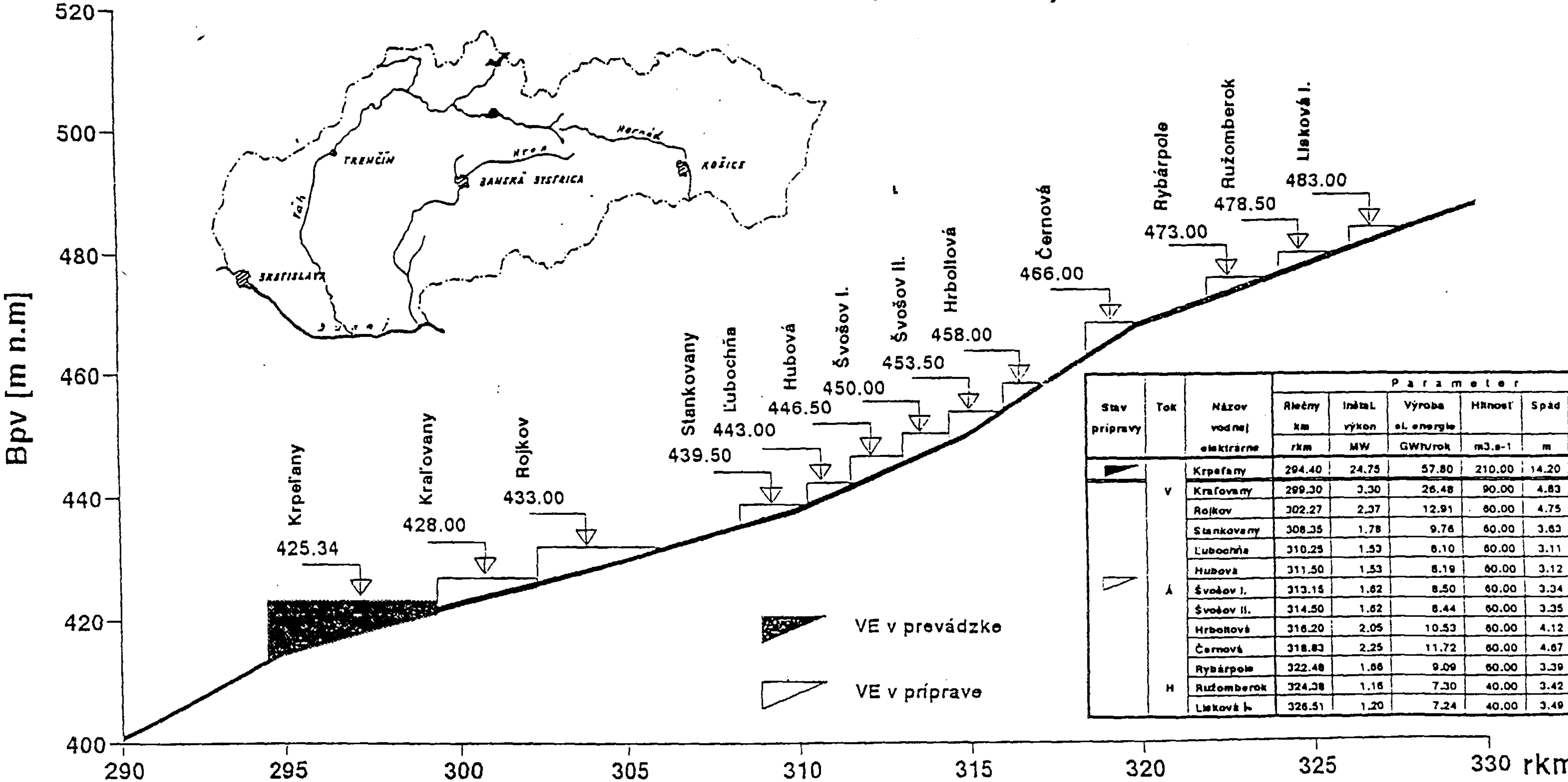
riečny km - river km

vo výstavbe - under construction

VE v prevádzke - VE in operation

VE v príprave - VE under preparartion

Návrh využitia hydropotenciálu
rieky Váh - H.V. III (úsek KRPEĽANY - LISKOVÁ)
v rkm 299.30 - 326.51 (Stav prípravy k roku 1996)



Stav prípravy	Tok	Názov vodnej elektrárne	Parameter					
			Riečny km	Inštal. výkon	Výroba el. energie	Hltnosť	Spád	Prevar. hladi
			rkm	MW	GWh/rok	m3.s-1	m	m n.
		Krpeľany	294.40	24.75	57.80	210.00	14.20	425.
	V	Kraľovany	299.30	3.30	26.48	90.00	4.83	428.
		Rojkov	302.27	2.37	12.91	60.00	4.75	433.
		Stankovany	308.35	1.78	9.76	60.00	3.63	439.
		Ľubochňa	310.25	1.53	8.10	60.00	3.11	443.
		Hubová	311.50	1.53	8.19	60.00	3.12	446
	Á	Švošov I.	313.15	1.62	8.50	60.00	3.34	450
		Švošov II.	314.50	1.62	8.44	60.00	3.35	453
		Hrbollová	316.20	2.05	10.53	60.00	4.12	458
		Černová	318.83	2.25	11.72	60.00	4.67	466
		Rybárpole	322.48	1.66	9.09	60.00	3.39	473
	H	Ružomberok	324.38	1.16	7.30	40.00	3.42	478
		Lisková I.	326.51	1.20	7.24	40.00	3.49	483

SE a.s., VET o.z.

Obr.6 (Fig.6)

A Proposal for Utilization of Hydropotential of the River Váh - H.V.III (KRPEĽANY-LISKOVÁ section) the River Kilometers 299.30-326.51 (status of preparation by 1996).

VE v prevádzke - VE in operation

VE v príprave - VE under preparartion

stav prípravy - preparation status

tok - stream

názov vodnej elektrárne - hydroelectric power plant name

parameter - parameter

riečny km - river km

inštal. výkon - installed capacity

výroba el. energie - electricity production

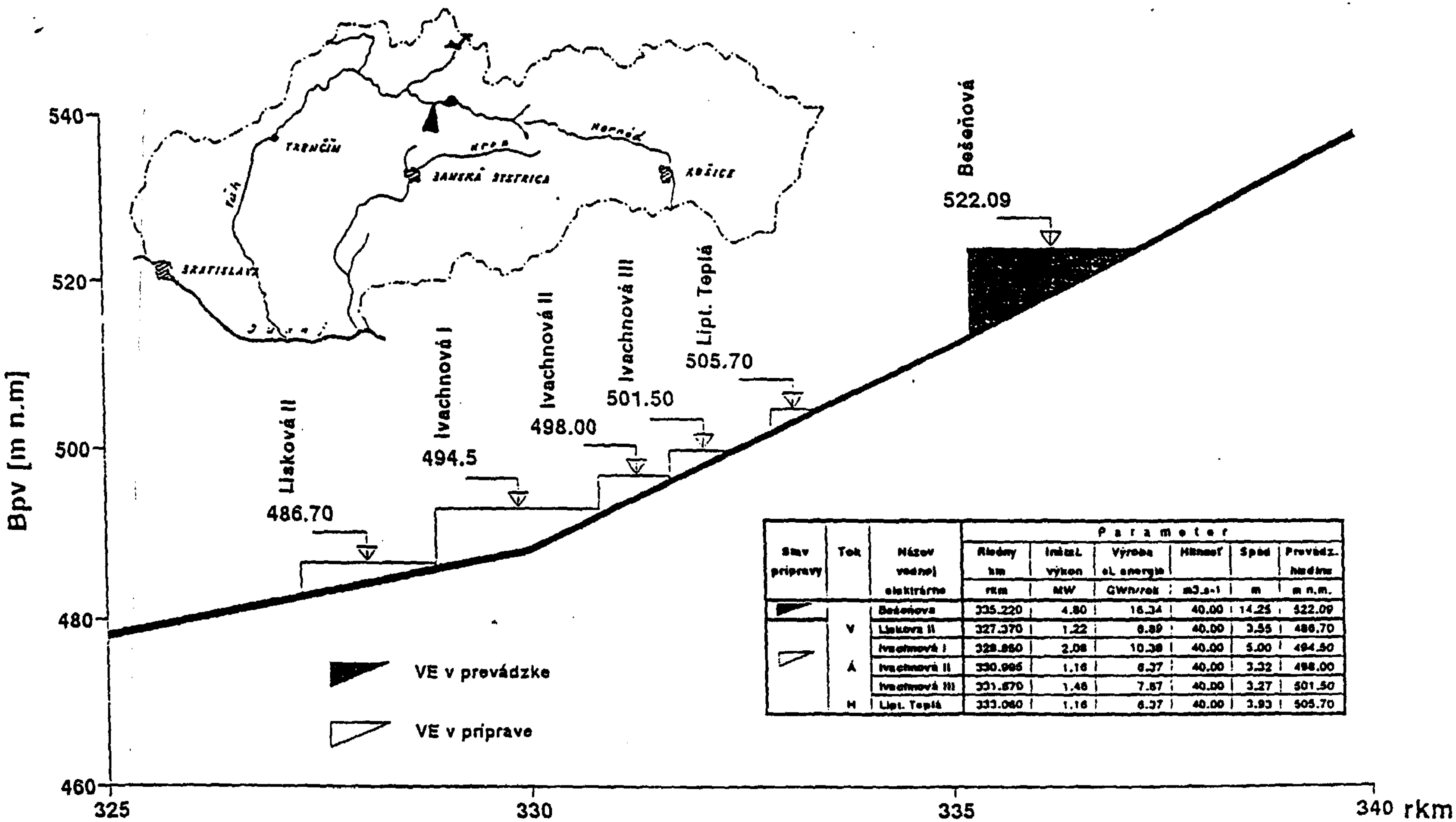
hltnosť - absorption capacity

spád - head

prevádzková hladina - operational level

Návrh využitia hydropotenciálu
rieky Váh - H.V. III (úsek LISKOVÁ - BEŠEŇOVÁ)
v rkm 327.37 - 335.22 (Stav prípravy k roku 1996)

obr. 7



Stav prípravy	Tok	Názov vodnej elektrárne	Parameter					
			Riečny km	Inštal. výkon	Výroba el. energie	Hltnosť	Spád	Prevádz. hladina
			rkm	MW	GWh/rok	m3.s-1	m	m n.m.
VE v prevádzke		Bešeňova	335.220	4.80	16.34	40.00	14.25	522.09
VE v príprave	V	Lisková II	327.370	1.22	6.89	40.00	3.55	486.70
		Ivachnová I	328.860	2.08	10.38	40.00	5.00	494.50
	Á	Ivachnová II	330.995	1.16	6.37	40.00	3.32	498.00
		Ivachnová III	331.670	1.46	7.87	40.00	3.27	501.50
	H	Lipt. Teplá	333.060	1.16	6.37	40.00	3.93	505.70

Obr.7 (Fig.7)

A Proposal for Utilization of Hydropotential of the River Váh - H.V.III (LISKOVÁ-BEŠEŇOVÁ section) the River Kilometers 327.37-335.22 (status of preparation by 1996).

VE v prevádzke - VE in operation
VE v príprave - VE under preparartion

stav prípravy - preparation status
tok - stream
názov vodnej elektrárne - hydroelectric power plant name
parameter - parameter
riečny km - river km
inštal. výkon - installed capacity
výroba el. energie - electricity production
hltnosť - absorption capacity
spád - head
prevádzková hladina - operational level

HYDROENERGETIC POTENTIAL OF THE SLOVAK REPUBLIC

situation by the end of 1995

hydroenergetický potenciál - hydroenergetic potetntial

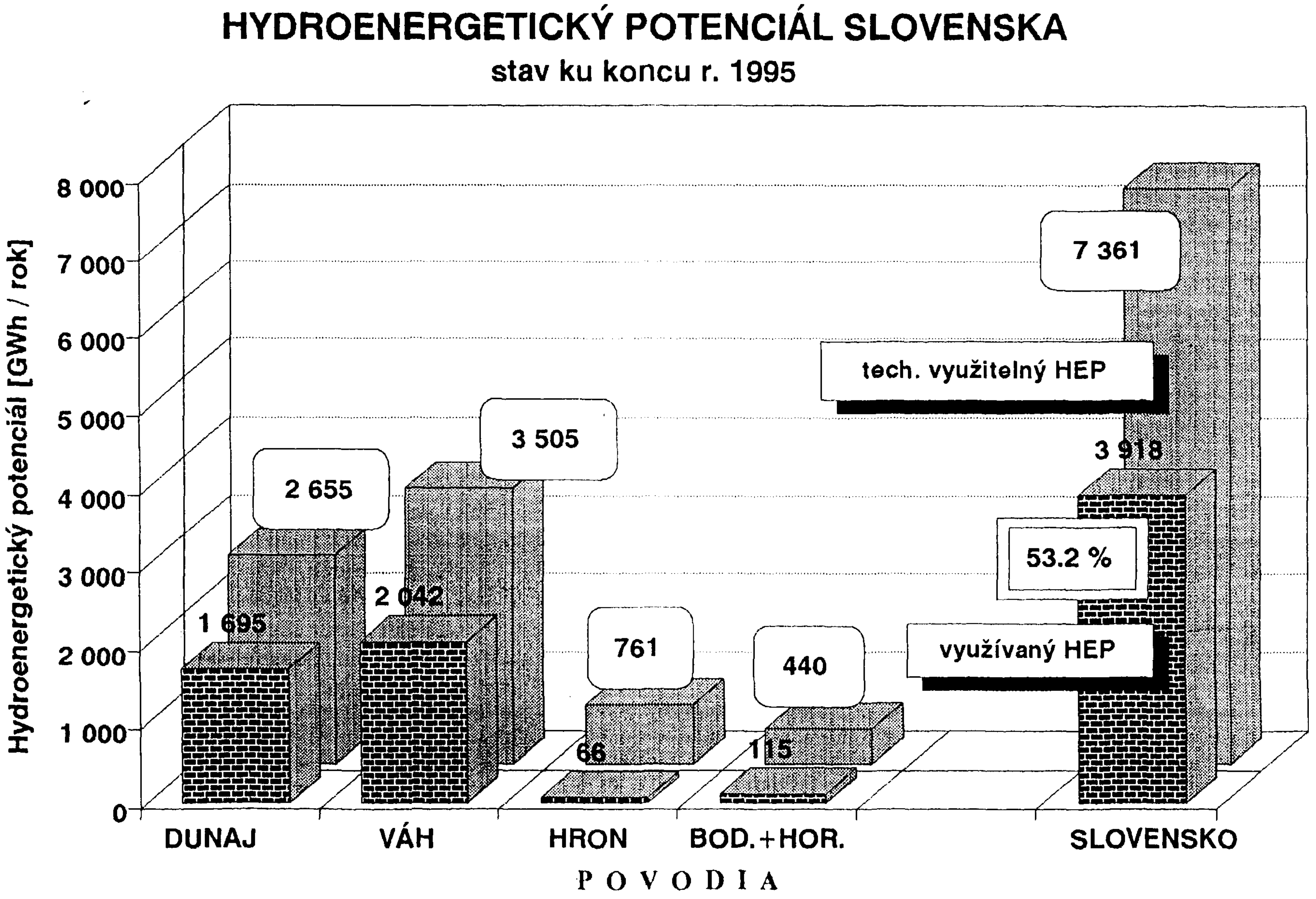
tech.využiteľný HEP - tech.usable HEP

využívaný HEP - HEP being utilized

Dunaj - Danube

povodia - basins

Slovensko - the Slovak Republic


HYDROENERGETICKÝ POTENCIÁL SLOVENSKA
stav ku koncu r. 1995
Hydroenergetický potenciál [GWh / rok]
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
2 655
1 695
3 505
2 042
761
66
440
115
7 361
3 918
53.2 %
tech. využitelný HEP
využívaný HEP
DUNAJ
VÁH
HRON
BOD.+HOR.
SLOVENSKO
POVODIA