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PROJECT OF REHABILITATION OF SMALL HYDROPOWER STATIONS IN RUSSIA INCLUDING HYDROPLUS FUSEGATES UTILISATION

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The electrical power system of Russia is experiencing serious difficulties of power supply in some regions of the country, despite considerable reserves of the installed capacity. The problem is caused by a number of factors, not least of which is the rise in energy production costs at thermal power stations, as a result of price rises in fossil fuel in the local market of Russia.
Under these conditions the effective operation of the Russian electrical power system is becoming increasingly reliant on its hydropower component, in which small hydropower stations are playing an ever more important role, especially for supplying local needs.

RAO «EES Rossii» (which is managing the electrical power system of Russia) is involved in working out a new strategic plan for hydropower development in Russia. The analyse involves the engineering and technical aspects of construction and refurbishment of small hydropower plants, especially in the densely populated central and north-west regions.

An extensive review of existing small hydropower stations allowed to the definition of requirements which the mechanical and hydropower equipment should fulfil, and the proposition of various systems as monoblock hydro generating units and Hydroplus fusegates.

1. PRESENT SITUATION OF SMALL HYDROPOWER STATIONS IN RUSSIA

Up to nineties the hydropower industry in the power system of USSR was developed at a fast pace. In 1990, its share in the installed capacity was about 15.4%.
Due to low production cost and hydropower being a renewable energy resource as well as high operational levels involved, the Hydropower Plants (HPPs) provided more than 21% (1994 figures) of the energy consumption in Russia, and in some regions the figure was more than 90%.

Most of the HPPs operating today should be considered as being in the medium and large size category having an installed capacity of over 50 MW. Many of them operate in a mode over the design capacity, often providing not only peak load but basic load supply as well.
In the European part of Russia the possibility of developing more large HPPs has been exhausted.

In accordance with the new power energy strategy of Russia the development of hydropower energy is therefore planned to be carried out using local resources, mostly by means of small and medium HPPs.

Current policy conducted by Russian government provides for the realisation of structural reforms in the historically formed power resources monopolies. In particular, actions are planned which will break the monopoly of electric power industry by means of the creation of a wholesale market with elements of State regulation.
The creation of an effective competition in the field of electric power supply, in a rather short time, will be stimulated by creation of small independent power generating companies operating small hydroelectric power plants (with capacity of 0.2 to 10 MW). The small HPPs would operate both in the global power energy wholesale market and independently from it, for one or several close small consumers.

Most of the unused water power potential of the European part of Russia exists in small and medium moderately sloping rivers which have quick floods and intensive drifting of floating ice sheets (floes).
Today only few small HPPs are operating in this area, they are also used for irrigation and water supply purposes.
Figure 1 shows an example of such a Hydropower Plant. This hydroelectric power station on the Istra river near Moscow was rehabilitated in 1995 utilising the existing turbines with the installation of additional " FLYGT" single-unit hydroturbine generators.

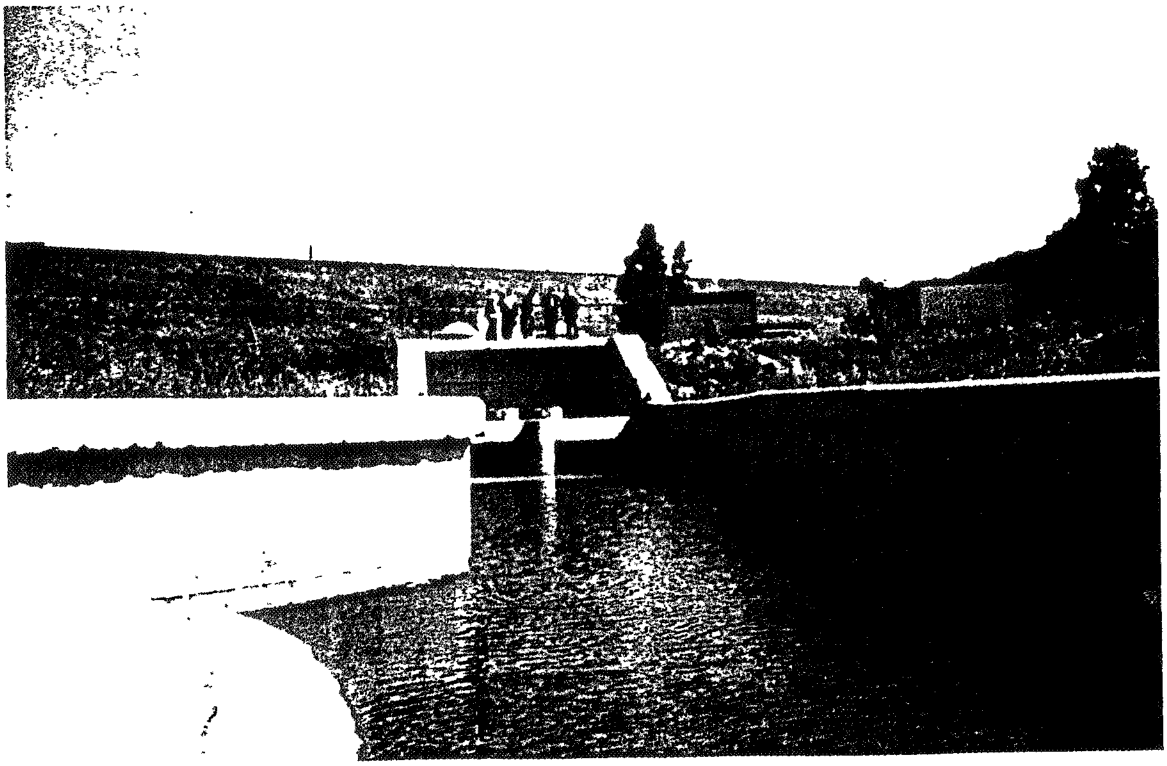

Fig. 1 :Hydroelectric Power Station on the Istra river Moscow area

Between the forties and the sixties, several thousand of small HPPs were constructed in the European part of Russia, with capacity ranging from 0.2 to 5 MW. Most of them were constructed according to a standard design, which included:

- a folding spillway located in the river bed;
- a concrete power house situated in the river bed comprising one to four power units, with open turbine chambers and vertical shaft Francis hydroturbines, of 0.15 - 0.5 MW capacity per unit, made by VOITH (Ltd), with power energy equipment supplied by SIEMENS (Ltd) along with Russian equipment;
- an operating head in the range of 3 to 10 m.;
- a reservoir located in the bed of the river which did not inundate the flood plain except during major flooding. The spillways were disassembled before the flood season and the HPPs stopped. The evacuation of floods was carried out in a mode close to the natural one, through the river bed and the flood plain and around the power house. This promoted a regular wash out of the deposited sediments in the river bed and the reservoir.

In the seventies and eighties, after creation of the integrated power network in the western part of Russia, the operation of such stations became economically not viable. Most of those mall HPPs were stopped and partially demolished.
However, the power house constructions were mainly left intact and after rehabilitation of the Hydropower Plants they can be re-used.

The role that small HPPs used to play in life of the province was of vital importance and their demolition influenced negatively the life of local population.
Everywhere, the demolition of earlier constructed small HPPs caused a deterioration of the ecological and social situation along small rivers of Volga and Don, in particular :

- non-regulated and non-supervised reservoirs creates a significant potential danger of dam failures and disastrous floods;
- the drop of water level in reservoirs caused the reduction of water table levels, the dry up of wells and the draining of water intakes. The situation of fish resources got worse;
- the demolition of a number of HPPs , which had ship-locks facilities caused the disappearance of local water transport routes;
- partially demolished, HPPs break the aesthetics of riverside environment and reduce the potential for water tourism and leisure activities.

Reconstruction of small HPPs is therefore seen as one of the most important developments in the hydropower industry in the western part of Russia.
Such reconstruction is also expected to contribute to much needed social, economic and environmental development.

2. REQUIREMENTS FOR MECHANICAL AND HYDROPOWER EQUIPMENT FOR SMALL HYDROPOWER STATIONS REHABILITATION

Programmes implemented at small HPPs after the second World War were aimed to minimising construction and operation costs, while providing the greatest increase in benefit. These aims are naturally as relevant now as they were then.

Engineering assessment of small hydropower plants on the rivers of Oka drainage basin, carried out in eleven regions in Central Russia, allowed for the formulation of the basic principles that had been adopted for general layout, structural design and construction.
The results may be summarised as follows:

- the main structures were usually placed in the river bed without extending earth-fill structures to the flood plain. The power house, spillway structure and bank abutments were located between the steep river banks.
  Earth fill structures on flood plains were rarely used. They were only used to protect the switchyard and transmission lines facilities or to create the flood diversion dikes to prevent the flooding of power house and non-submersible structures, during the extreme flood events. The tail parts of these diversion dikes were protected with rubble;
- the design discharges corresponded to the floods with 5 to 20 per cent annual probability of occurrence.
  The control equipment of the spillway structures (either rotating girder or vertical tilting gates) were placed on a concrete sill at a low elevation. During the annual floods they provided practically complete opening of the river bed section to allow the passing of the flood discharges;
- for flood events of very low probability the design permitted complete submergence of spillway structures, bank abutments, the powerhouse (excluding generator hall), ship-lock chambers and any mechanical equipment having no electric parts.
  Flood discharges were passed not only through spillway structures but also around the main structures, through the flood plain. In this case there was no potential head on the structures and the flood regime was very close to the natural one;
- the disassembling of the control gates and corresponding reservoir draw-down before the annual flood period also ensured the washing out of previously deposited sediments;
- power house design was simplified allowing operation without the scroll chambers and turbine duct metal lining. The design also permitted submersion of all powerhouse elements below the generator hall floor elevation;
- diversion canals built during the construction period were preserved for use in the case of rehabilitation of the structures.

All the above mentioned design parameters can be successfully applied in the rehabilitation of small scale hydropower stations as well as for construction of new stations on the moderately sloping rivers in Russia, in conjunction with the provision of modern hydroturbines and mechanical equipment.

Equipment for small HPPs, constructed in accordance with the listed above principles, should meet the following requirements.

The mechanical equipment should :

- need minimal expenses for installation, during the rehabilitation of earlier constructed small HPPs;
- operate automatically with a minimum of maintenance and supervision;
- have the possibility of being manufactured at non-specialised factories or at the construction site, as well as a having the possibility of being standardised;
- be adaptable to different climate zones of Russia.

The hydropower equipment should :
- operate automatically;
- have a simplicity of layouts (without a power house, for example) and allow standardisation of small HPPs construction;
- allow for its quick repair and replacement.

3. DESCRIPTION OF VARIOUS SOLUTIONS PROPOSED FOR HYDROPOWER EQUIPMENT AND MECHANICAL EQUIPMENT

Application of Hydroplus System fusegates at the spillway structures of the moderately sloping rivers complies with the design requirements mentioned here above.

The fusegates are installed on a low reinforced concrete sill which retains the water and creates the potential head at the power station.
Moderate floods are evacuated over the fusegates which act as an uncontrolled spillway. During exceptional floods the fusegates automatically tip of the sill, one after the other, in a predetermined sequence. The number of the fusegates tipping depends on the flood magnitude. For the design flood all the fusegates tip off, opening the spillway spans up to the entire river cross section.

Manufacturing fusegates is simple and could be performed by non-specialised factories. No operation equipment is needed (such as hydraulic activators, electricity, etc.) which minimise the construction and maintenance costs.
Furthermore installation on the existing spillway sill can be achieved with very limited civil works.

Submersible single unit hydroturbine generators " FLYGT" are an example of advanced equipment for hydropower plants.
The power house design is simplified because they do not need construction of complex inlet and outlet turbine ducts, which reduces significantly the construction cost.
Moreover, during extreme floods the power house can be completely submerged without damage for the hydropower equipment.
The submersible hydroturbine generators can be installed at most of the small hydropower plants assessed, without significant works to the power house foundation and without reducing the potential head and discharge.

4. MODEL TESTS CONDUCTED TO ADAPT HYDROPLUS FUSEGATES TO RUSSIAN CONDITIONS

During winter the climatic conditions in the northern regions of Russia are extreme. The ice thickness in reservoirs often reaches 1m.
In spring period floods are caused by snow and ice melting. In the reservoirs the ice cover break-up occurs in the beginning of the flood season. Ice floes pass over the

spillway during high floods period. The ice thickness during this period is in the range of 0.35 to 0.8 m.

In order to analyse the reliability of fusegates in such extreme conditions, two model testing programmes were conducted in collaboration with renowned laboratories.
The following points were analysed :
- ice action on fusegates during winter in very cold regions and when the dam reservoir remains full, especially the impact of thermal expansion and reservoir water level changes.
- influence on fusegate operations of ice floes combined with exceptional floods (rivers similar to those of the northern regions of Russia in spring period).

The first study was carried out at the Institute for Marine Dynamics of the National Research Council of Canada, in St John's, Newfoundland.
The second one was conducted by the Hydraulic Laboratory of the Scientific Research Institute of Energy Structures, in Moscow, Russia.

Details concerning the scope and the main results of the model tests were published in the International Journal on Hydropower & Dams, issue three, 1996, in an article headed « The reliability of fusible gates in ice-affected environments » [2].

The main conclusions of the model testing programmes were as follows:
- during winter, in very clod regions, if the reservoir remains full, thermal expansion or a change in reservoir level often cause no movement of the fusegates at all. In extreme conditions they may lead to a very small rotation (less than one degree) with no effect on fusegates stability;
- In the case of rivers similar to those of the northern regions of Russia, one of the following protective measures should be undertaken to make provision to deal with large ice floes:
  - incorporation of ice breaking structures, which are widely used in northern regions of Russia to protect spillways equipped with conventional gates;
  - installation of very wide fusegates to increase the distance between adjacent inlet wells, which constitute the only obstacle to the free passing of ice floes over the fusegates;
  - the installation of inlet wells in the spillway abutments, which eliminate the obstacle to the ice floes evacuation. This fusegate design has been applied at Puylaurent [3] arch dam in France (moderate climatic conditions) for other purposes than ice floe evacuation (see figure 2).

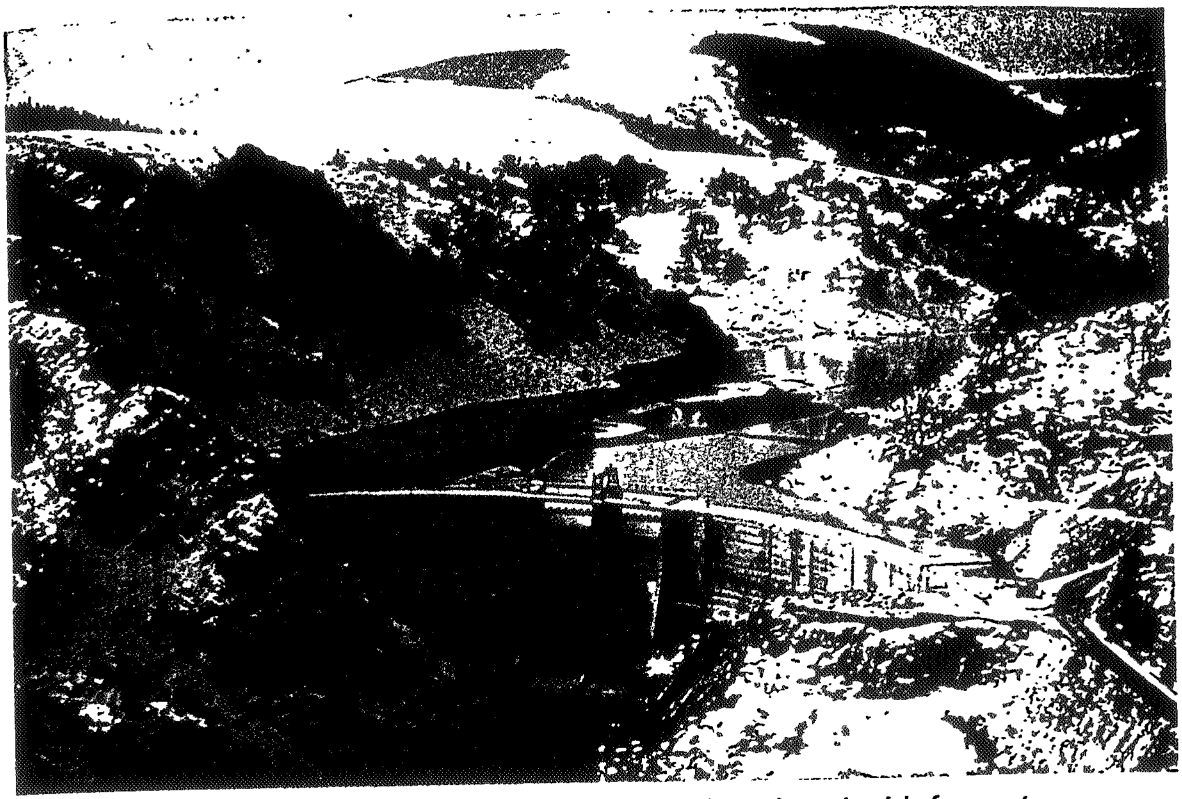

Fig 2 : PUYLAURENT arch dam (EDF, France) equipped with fusegates
The inlet wells are installed in the spillway piers
Photo : LA PHOTOTEQUE EDF , MARC MORCEAU

5. KHOROBROVSKAYA PILOT PROJECT AND FIELD TESTS PROGRAMME TO BE ACHIEVED AT THE PILOT PROJECT

" RAO EES ROSSII" has prepared the project of an experimental hydropower plant (Khorobrovskaya scheme) on the Nerl river in Yaroslavl region. The station will be constructed at the site of an old dam destroyed in the seventies.
The Nerl river is a tributary of the Volga river and flows in a typical central Russian climatic and topographical conditions.

At the experimental HPP, it is planning to analyse the efficiency of the application of Hydroplus fusegates (for flood control) and single-unit submersible hydropower generators developed by "ITT FLYGT AB".
It is also anticipated to test other technologies which are capable to increase the efficiency of construction and rehabilitation of small hydropower stations.

The available upstream head at the experimental hydropower plant is 3.5 m. The maximum design discharge of the spillway is 420 m^3/s (100 year flood).
The spillway will consist of a low reinforced-concrete sill equipped with 12 Hydroplus fusegates 1.75 m high and 3 m wide.
Six fusegates are designed to tip for flood evacuation purposes, whilst the other six fusegates are installed for experimental purposes.

The small and moderate spring floods are evacuated over the fusegates. The first fusegate overturns for a flood with an annual probability of 10%. A flood with an annual probability 5% passes through 4 overturned fusegates. All six fusegates overturn for the 100 year flood (420 m^3/s).

In comparison with the free overflow spillway design, the Hydroplus fusegates allowed to reduce the spillway length by 35% and to reduce the maximum head above the normal reservoir level by 50%. Reduction in the maximum water level is very important for the rivers of central Russia because these rivers flow in plains. In this case, flooding of territories during spring high floods will be minimal.

The six principal fusegates were developed specially for winter and spring conditions of Russia, as the ice thickness in the reservoir may exceed 60 cm. For these fusegates the water supply system (for creating the uplift pressure in the fusegate chamber) was adapted and protected from freezing. The inlet wells were installed in the piers of the spillways and are connected to the fusegates chambers through conduits inside the sill concrete.
Emergency stoplogs can be installed upstream each fusegate to reduce the drop of reservoir level in the case of fusegates tilting during exceptional floods and if the opening of the entire section of the river is not necessary.

Two turbines FLYGT are installed at the experimental HPP. The global capacity is 150 kW.

The fusegates elements freezing and deformations of steel elements under ice loads during winter will be investigated at the experimental HPP spillway .
The experimental HPP design is shown on figure 3.

6. SIGNIFICANCE OF THE SMALL HYDROPOWER PLANTS REHABILITATION PROJECT

The reconstruction of small HPPs in the Western part of Russia is one the most interesting guidelines in the Russian hydropower industry.
By utilising existing reservoirs no additional land need to be allocated. Furthermore, by utilising the preserved existing access roads, communication equipment and main constructions, by installing modern equipment and by adopting appropriate design and method of construction, the construction cost and operation expenses of small HPPs will be reduced substantially.

The existence of networks of small HPPs on the Volga, Don and other big Russian rivers tributaries will essentially reduce the need of power production of large HPPs. This will create prerequisites for partial reduction of head at large HPPs, reduction of the flooding of nearest territories and improvement of the ecological situation.

The rehabilitation of some small HPPs is an economically successful solution to guarantee the supply of local power needs in Russian provinces, especially in the regions disconnected from the United Electric Power System of Russia.

If compared to thermal power stations, small HPPs are not influenced by fluctuation of the fuel price, do not need deliveries of product for their operation and are ecologically clean.

The operation mode of HPPs can cover both peak and basic loads. The availability of guaranteed and solvent consumers for small hydropower generation capacities should not be a problem, even in the least developed regions.

The reservoirs of the rehabilitated small HPPs would be used for other purposes such as water supply, recreation, fishing, water transportation, etc.
The success of this project will hopefully solve most of the ecological, social and economic problems in small rivers areas caused by the destruction of small hydropower plants constructed earlier.

Bibliography :

1. **S. Lachtchenov, V. Semenkov**, « The problem of small scale hydropower stations on the rivers of central Russia », Twenty seventh IAHR Congress , USA, 1997.
2. **S.J. Jones, D. Spencer, V.B. Rodionov, M.E. Lounatsi and A. Aït Alla**, « The reliability of fusible gates in ice affected environments », Hydropower & Dams; Issue Three, 1996.
3. **B. Mahiou**, « Puylaurent Dam », Q70 R3, Eighteenth ICOLD Congress, Durban South Africa, November 1994.