## INNOVATIVE HYDROPOWER DEVELOPMENT IN AN URBAN ENVIRONMENT DEVELOPPEMEMT DE LA HYDROELECTRICITE INEDITE EN MILIEU URBAIN

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#### 1. Background Introduction

Considering the generation of electricity, Europe features a wide variety of legislative principles and peculiarities, depending on the geographical situation, the political environment and the historical development. In particular, the share of hydropower within the total electricity generation varies considerably between European countries, ranging from a negligible figure (United Kingdom) up to 99 % (Norway) <u>Fig. 1</u>. For alpine countries such as Austria and Switzerland hydropower plays a paramount role in their endeavours towards a sustainable development by production of clean and renewable energy.



Fig. 1: electricity generation in Europe Production d'électricité en Europe

All Countries within the European Union (EU) are urged to increase the share of renewable energies, including hydropower, in their total mix of energy production. The EU - Directive on renewable energy sets goals of doubling the share of "renewables" in the total energy consumption to 12% by 2010, and increasing the renewable energy share in electricity generation from 14% in 2001 to 22% by 2010. For countries with an adequate potential, hydropower is one of the options to achieve this goal.

#### 1.1. Electricity Generation in Austria Production d'électricité en Autriche

In 2002, Austria had a total electricity generation of 62.700 GWh about 42.000 GWh of which was accounted for by hydropower plants. Only 20.400 GWh were produced by thermal power and the remaining amount of about 300 GWh was generated from other sources. In accordance with EU Internal Market Directive RL 96/92/EC, Austria started liberalization of its electricity market in 1999 and finalized its total liberalization on 1<sup>st</sup> October, 2001.

Austria's largest energy producer is "Verbund", a public company operating 123 power plants in seven of nine Austrian provinces and covering almost 50% of Austria's power consumption. The total firm power of all Verbund power plants is 8.9 GW, the mean output capacity (yearly average) of the hydropower stations is about 28 TWh. The major part of the hydropower capacity is bundled in the VERBUND-Austrian Hydro Power AG (AHP) Fig. 2.



Fig. 2: Hydropower plants of the AHP Installations hydroélectriques de AHP

#### 1.2. The Significance of Hydropower L'importance de l'énergie hydraulique

Utilising hydropower as a clean and emission-free way of generating electricity began in the late 19<sup>th</sup> century and has become a basic instrument of development ever since. In particular, the industrial progress after World War II is strongly associated with hydropower which covers about 70% of the national electricity generation, to a bigger part through run-of-river schemes.

Apart from run-of-river plants in the lowlands  $\underline{Fig 3}$ , numerous storage power stations were constructed in the western alpine regions, primarily covering peak load demand. "Kaprun" storage power station  $\underline{Fig. 4}$  – now a landmark on the edge of "Hohe Tauern" National Park – represents the first large-scale power station, celebrated as a symbol of reconstruction and progress.



Fig 3: Ybbs run-of-river powerplant Centrale au fil de l'eau d'Ybbs



Fig. 4: Kaprun storage power plant Centrale à reservoir de Kaprun

In addition to the large-scale hydropower stations about 1.300 small and smallest-scale hydropower stations feed into the network, enhancing a decentralized system of primary supply.

#### 1.3. Environmental, Social and Economic Aspects Aspects environnementaux, sociaux et économiques

In the pioneering days of hydropower construction attention focussed mainly on the technical and economic aspects. In the course of the past years, however, environmental issues and public interest started to gain increasing importance and any further development is now subject to high environmental standards and an intense public participation process.

There is a large variety of benefits from hydropower plants, in particular from run-of-river development which not only generates electricity but also serves multiple purposes, such as

- preservation of natural habitats
- drinking water supply
- irrigation of wetlands
- ground water management
- improvement of infrastructure
- flood prevention
- river navigation
- tourism, recreation

#### 1.4. Hydropower from the Danube River Energie hydraulique sur le Danube

The Danube flows through Austrian territory on a stretch of 350 km with a hydraulic slope equalling that of an alpine river: more than 150 meters of head between the German and the Slovak border and an average flow of about 1500 m<sup>3</sup>/s provide an enormous energy potential. Since the end of the 1950's, when "Ybbs-Persenbeug" the first hydropower station on the Danube was put into operation, the river has been utilized to generate power.

Today nine run-of-river power stations on the Austrian stretch of the Danube with a maximum capacity of 2.060 MW, generate a total of more than 12.000 GWh/a, i.e. approximately 20 % of the total Austrian power

production. The Danube has become fully navigable, and the risk of floods has been reduced considerably in many regions. The ultramodern and highly efficient Vienna/Freudenau hydropower scheme, commissioned in 1997, is the newest in this power chain on the Austrian section of the Danube River.

#### 2. The Vienna/Freudenau Hydropower Scheme La centrale hydroélectrique de Vienne/Freudenau

Freudenau HPP <u>Fig. 5</u> was erected in the years 1993 to 1997 and is located in the heart of Central Europe within the boundaries of the city of Vienna which has a population of nearly two million. Like all other power plants on the Danube, it has contributed significantly to improving conditions for navigation and to more efficient flood control. In its complexity, however the Freudenau plant differs from all earlier Danube power stations.



<u>Fig. 5</u>: Freudenau hydropower plant in Vienna Centrale hydraulique de Freudenau à Vienne

#### 2.1. Project Development Le développement du projet

Project development started in 1985 when first project drafts and an interdisciplinary study regarding the detailed location where worked out. From 1986 to 1988 a contest entitled "Opportunities for the Vienna Danube Area" was organized. Hydro-power experts, architects, urban planners, landscape architects and ecologist participated in this contest. It was the aim of this contest to select the optimal proposals for the architectural design of the barrage and to assure a harmonious integration of the power plant into its environment, to achieve an ecological design of the reservoir area and to meet urban development criteria. Apart from the generation of electricity the following objectives for the Freudenau hpp were defined in this planning process:

- Termination of the scoring of the river bed as a result of river training
- Improvement of the ground water regime in the surrounding areas with special respect to local wetland areas as well as urban regions
- Improvement of river navigation conditions
- Securing of the total flood protection for the city of Vienna
- Improvement of local water management (water supply, waste water treatment)
- Development of ecological structures, especially in the riparian areas

Subsequently, the project was submitted to the responsible water authority and subjected to an environmental impact assessment. This assessment was finished with a positive statement in January 1991. Hence, the water authority issued the basic permit for the implementation of the project. By June 1992, all other permits required for starting construction of the power scheme had been obtained.

Most remarkably, an extensive public participation process was set going to accompany the planning and to include the population in the project development. In May 1991, a public referendum was held for the whole population of Vienna, asking whether they agree with the construction of the hydro scheme. The outcome showed that 72% of the participants approved of the power plant. This referendum was due to a special request by the Mayor of Vienna.

#### 2.2. Main Characteristics Caractéristiques principales

2.2.1. General Specifications Spécifications générales

The following table shows the general characteristics of Freudenau hpp:

Item	Specifications	
River System	Danube	
Catchment Area	101,731 km2	
Туре	Run off river (no storage)	
Power house	No. of units	6
	Max. capacity	172 MW
	Generation	1,052 GWh/a
	Max. discharge	3000 m <sup>3</sup> /s
Spillway	No. Spans	4 (each 24m)
	Gates	Tainter gates with flap
Navigation locks	No. of chambers	2 (24 x 275 m each)
	Upper head	Rotary segments with flaps
	lower head	Mitre gates
Fish pass	Туре	natural
	discharge	1.2 - 7 m³/s
Backwater area	length	28 km
	No. of Pumping stations	50

#### Fig. 6: General specifications of Freudenau HPP

Spécifications générales de la centrale hydroélectrique de Freudenau

Construction of the barrage started on October, 1<sup>st</sup> 1992. During construction, three million tons of construction materials were used, 6.6 million m<sup>3</sup> of excavated materials were moved, 1.3 million m<sup>3</sup> of concrete were poured in place and some 24,300 tons of reinforced steel were integrated into structures.

#### 2.2.2. Barrage Barrage

The barrage of Freudenau HPP consists of four sections performing different functions:

- Powerhouse Fig. 7
- Spillway
- Navigation lock
- Fish pass

The power house is located at the center of the river between the spillway on the left bank and an artificial island with the lock filling and emptying structures, the assembly hall and the administration building. The navigation locks are situated between this artificial island and the right bank of the river.



Fig. 7: Cross Section of the turbine Coupe de la turbine

#### 2.2.3. Backwater area Région d'amont

The length of the backwater area is 28 km. A series of measures were taken (sewage treatment plants, etc.) to safeguard a water quality of at least category II. Besides, the implementation of a ground water management system <u>Fig. 8</u> and additional measures related to urban infrastructure (e.g. raising the existing bridges across the Danube) were part of the works and thus were financed by the project.

#### Urban section (City of Vienna)

The right river bank was designed as a park like zone for recreation activities. There are harbors for pleasure navigation, promenades, restaurants and the urban live has developed significantly. The left bank was ecologically designed providing for a bypass channel at the barrage (fish ladder with fish way).

#### **Rural section (Province of Lower Austria)**

The river bank was landscaped for optimum integration into the environment. For this purpose, the "old Danube arms" were reconstructed and transformed into "fish ladders", "fish ways", "feeder gates" and ponds. This also led to a rising of the water levels in the existing surface water bodies.





Surveillance Program: Using an elaborate monitoring net

Off-line monitoring: Downgrading wells

Fig. 8: Ground water management system Système de gestion des nappes phréatiques

#### 2.2.4. Downstream area Région d'aval

In the downstream area a national park "Donau-Auen" was established in 1996. In order to avoid additional scouring of the river bed in the section between Freudenau hpp and the Austrian - Slovakian border artificial gravel feeding (160.000 m<sup>3</sup> per year) was started with commissioning of the scheme.

# 2.3. The "Donaukanal" Tributary L'affluent "Donaukanal"

# 2.3.1. History and Significance for the City L'histoire et l'importance pour la ville

The original Danube region in Vienna was formed by wide areas of alluvial forests and widely braided tributaries of the Danube River. The river often changed the course of the main tributaries after floods and highwater periods. Over the past centuries the City of Vienna has often suffered from floods of the Danube River. Therefore the first regulation of the Danube River in the region of Vienna took place between 1870 and 1875. The meandering tributaries were cut off and the today's main river bed of the Danube took shape. The "Danube Channel", a formerly main tributary of the Danube crossing the city centre emerged from the regulation Fig. 9.

During the  $19^{th}$  century the Danube Channel was extended to fit the nautical needs. In 1872 the so called "swimming gate" was designed by engineer "Wilhelm von Engerth" for regulating the inflow into the Danube Channel and for ice defense <u>Fig. 10</u>. In 1898 the swimming gate was replaced by a "needle weir", a moveable weir with a width of 30 m mounted at the so called "Schemerl Bridge", and a ship lock was constructed. The architectural design of the weir and the administration buildings was carried out by the famous Austrian architect Otto Wagner <u>Fig. 11</u>. Because of the creativity and special design of the ensemble as a whole it is now preserved as a historical site.



Fig. 9: City map of Vienna plan de la ville d'Vienne



- Fig. 10: Arial view of the weir and ship lock in Nussdorf Vue aérienne du barrage et de l'écluse de la centrale Nussdorf
- <u>Fig. 11</u>: Upstream view of the Schemerl Bridge and administration building Vue de la région d'amont, du pont "Schemerl" et du bâtiment administratif

In the course of works for an improved flood protection for the city of Vienna the ship lock was adapted from 1964 - 1966, and the hydraulic structures at the "Nussdorf" weir were reconstructed to meet the flood protection requirements. The needle weir from 1898 was replaced by two redundant rotary segments, one abaft the other, downstream of the Schemerl Bridge.

The urban riparian zone alongside the Danube Channel is extensively used as a recreational area, with welllit promenades and bicycle paths, nature-oriented and sunbathing areas, as well as pubs and restaurants. The ongoing project "Spittelauer Lände", an 3.350 m<sup>2</sup> architectural project, designed and planned from the international renowned architect Mrs. Zaha Hadid, and financed by the municipality of Vienna, emphasizes the importance of the area alongside the Danube Channel for the urban development in the city of Vienna.

#### 2.3.2. Hydro-Energetic Potential Potentiel hydroénergétique

Due to water storage by the barrage at Freudenau the water level at Nussdorf was raised by approximately four meters. The discharge into the Danube Channel has to be permanently reduced by means of the rotary segments according to specified operation rules for the weir and the ship lock and depends on the discharge in the Danube River.

In normal operation, the inflow during the winter period (December to March) is constant at 70 m<sup>3</sup>/s, during the summer period the flow is between 80 m<sup>3</sup>/s and 225 m<sup>3</sup>/s. During floods the admission is reduced in accordance to the water level at "Schwedenbrücke" – a gauging station in the city center – until the weir is closed.

#### 2.3.3. Options for a Hydropower Plant Diverses options d'une centrale hydroélectrique

The first consideration of a power plant at Nussdorf was made during an early stage of construction of the Freudenau scheme in the 1990's. Based on a Feasibility Study an architectural contest was arranged in 1992. The presented concepts varied from barrages situated upstream and downstream of the Schemerl weir to an additional channel between the Danube and the Danube Channel. It was not yet possible to integrate a plant in the existing structures. Hence, none of the projects was further pursued due to technical and economical reasons.

The realization of the "Nussdorf small-scale hydropower project" first became economically viable following the passing of new "green power" legislation and the availability of the new HYDROMATRIX<sup>®</sup> technology. In 2002 VERBUND - Austrian Hydro Power AG reassumed the initiative together with two local utilities, EVN and WIENSTROM and elaborated a Feasibility Study. The study analyzed three general alternatives using the matrix technology within the weir:

- replacement of the second rotary segment with a new segment and integrated matrix-turbines
- a steal rack containing the matrix-turbines build on a bottom sill
- an over flown weir-sill with integrated matrix turbines

Following problems were assessed during the study:

- technical feasibility including investment costs and implementation schedule
- economic efficiency taking into account the green power legislation
- achievement of the local requirement (e.g. protection of the historical ensemble, operation rules)

Under consideration of the impact on the existing historically preserved ensemble and the profitability the over flown alternative with integrated matrix turbines was recommended for succeeding examination.

#### 3. The "Matrix" Technology La technologie "Matrix"

The matrix turbine represents an innovative technology especially for application in the range of small hydropower plants. The term "matrix turbine" already includes the most important feature: small, identical units are arranged within a frame in the shape of a matrix Fig. 12.

#### Specific features:

- propeller turbine
- asynchronous generator
- braces
- matrix frame
- flaps



<u>Fig. 12</u>:

Basic concept of a matrix turbine Concept de base de la Matrixturbine

Each machine unit consists of a squirrel-cage asynchronous generator driven by a turbine with fixed runner blades, which is attached directly to the generator shaft. Both parts are surrounded by the driving water. Each unit within the matrix frame can be separately operated by an independent closure, if required. The dimension of each unit is approximately 1x1x3m. All necessary energy and control cables as well as hydraulic lines are conducted within the matrix frame up to the specific interface.

The matrix turbine converts the water's mechanical energy to low voltage electrical energy. The generators are connected in parallel and their power will directly supply a low voltage grid via a connected switch yard, or it will feed into a transmission grid via a transformer, which converts it to a higher voltage level.

#### 3.1. Pilot Project at Freudenau Ship Lock Projet pilote dans l'écluse de Freudenau

The first "Matrix turbine" – a pilot project partly funded by the European Commission under the Thermie program – was installed in a ship lock at Freudenau/Vienna hpp  $\underline{Fig. 13}$ . This kind of application is a most challenging one because of the following requirements.

The module is designed to generate power during both the filling and emptying of lock operation. This requires the turbine-generator units to operate in both flow directions with variable heads (from maximum to zero during each locking procedure) and with more than 20 on- and off- switches per day. For ships passing the locks at Freudenau there must not be a noticeable difference between lock operations with or without the turbine and in case of a major failure the Matrix turbine has to be removed from the filling/ emptying channel within an hour Fig. 14. Number of units:25Unit output:200 kWSpeed:500 rpmHead:0 m - 10.3 mPlant capacity:5 MWAverage yearly production3.7 GWh



- Fig. 13: Technical Data of the Freudenau Matrix Données techniques du matrix Freudenau
- Fig. 14: Matrix turbine during Installation Matrixturbine en cours de montage

#### 3.2. Advanced Concept Concept inédit

The HYDROMATRIX® turbine-generator solution developed by VA TECH HYDRO is a low cost solution for installation of hydropower at low head sites with existing dam and gate structures. Such projects which cannot be developed in a feasible way by use of conventional turbine-generator design can now be developed profitable using the HYDROMATRIX® approach. The design utilizes a factory assembled "grid" of small propeller turbine-generator units. The module is shipped to the site where it is installed into the existing water passage. When flows in excess of the module's capacity must be passed, the HYDROMATRIX® module may be raised or removed from the operating position like a gate.

In order to achieve technical and economical feasible applications, the following main conditions have to be observed:

- Available plant discharge from ~ 100 m<sup>3</sup>/ s (3, 500 cfs)
- Available head from 3 m up to 30 m (10 100 feet)
- Minimum submergence 1.5 m (5 feet) below tail water
- Unit output from 200 kW up to ~ 700 kW
- Close grid connection
- Structure available & suitable for Matrix technology

The following main advantages make HYDROMATRIX® attractive:

- Clean & environmentally friendly energy (KYOTO- protocol)
- Use of existing weir structures minor civil construction, no geological risk and no additional land usage
- Standardized modular concept
- Short project schedule (1 1.5 years)
- HYDROMATRIX® modules removable at flood conditions
- Keep existing river flow pattern
- High availability
- Innovative application of a proven technology

#### 4. The "Nussdorf" Hydro Project La centrale hydroélectrique de "Nussdorf"

In the bidding procedure in 2003, the Bidding Consortium Nussdorf, consisting of VA TECH HYDRO, PORR TECHNOBAU and VERBUNDPLAN as consortium leader, proposed a HYDROMATRIX<sup>®</sup> solution in the stilling basin of the Schemerl Weir in Nussdorf. The HYDROMATRIX® concept was evaluated by the owner and a pertinent contract has been awarded by VERBUND-Austrian Hydropower AG and its project partners EVN and Wienstrom.

The ongoing hydropower plant project Nussdorf is situated in the stilling basin (downstream weir) of the Schemerl weir <u>Fig. 15</u>. It consists of a 30 m long, 12 m wide and 7 m high over flown weir sill with attached pneumatically operated spillway gates. The operating building will be built on the left river bank, next to the retaining wall of the weir. The operating building is connected with the service gallery of the weir sill via an access shaft, which is integrated in the operating building and covered with a moveable tin roof.

The architectural design of the operating building happened in cooperation with the Department of Monument Protection – Section Technical Monuments. It is designed as a one-storey fair-faced concrete building with a rectangular outline of approx. 12.1 x 15.5 m and covered with a rolling pre-coated tin roof Fig. 16.

The 12 turbine chambers at the bottom of the weir host the turbine-generator units (TG-units). Each turbine chamber can be locked pneumatically with the intake gate and the draft tube gate and dewatered without impacting the other TG-units. The turbine chambers are equipped with a lifting gear running on two rails and are separated from the service gallery with bolted pressure covers.

The rakes of the trash rack are mounted in front of the intake of the TG-units in the existing weir bottom and at the weir crest. It is build of six circular screens and equipped with six screen cleaning machines.





Fig. 15: Schematic lay-out of Nussdorf hpp Représentation schématique de la centrale hydroélectrique Nussdorf

Fig. 16: Operating building La salle de l'exploitation

#### 4.1. Basic Requirements Exigences fondamentales

After commissioning of Nussdorf hpp, the discharge of the Danube Channel will be controlled by the plant itself. Therefore it was a main design criterion that the inflow according to the operation rules for the weir and the ship lock Nussdorf can be fulfilled during all operating conditions, even if the turbines are switched off.

Rejection surge has to be widely prevented as the Danube Channel is a navigation channel and the riparian zones are used as recreational area. Due to nautical reasons the construction works within the stilling basin

of the weir have to be performed during winter from November to March, when the ship lock is used as the inflow structure for the channel. As the power plant will be erected within a historically preserved area the architectural design had to be clarified with the Department of Monument Protection.

#### 4.2. Technical Concept Concept technique

The HPP Nussdorf will be equipped with an independent control system and will operate automatically during normal operation <u>Fig. 17</u>. In case of floods the rotary segments will be closed and the power plant will be switched off. The visualization of the control system will be also available at Freudenau.

The flow in the Danube Channel varies between 70 m<sup>3</sup>/s and 225 m<sup>3</sup>/s and depends on the discharge of the Danube River. As the maximum turbine discharge is 132 m<sup>3</sup>/s, all water exceeding 132 m<sup>3</sup>/s will flow through the attached pneumatically operated spillway gates. In case of maintenance of one or more turbines, the discharge of the spillway gates will be increased. As soon as the capacity of the spillway gate is reached, a turbine chamber will be opened with the TG-unit in no-load operation.

The 12 TG-units will be installed after the erection of the weir sill <u>Fig. 18</u>. Therefore the TG-unit will be lifted into the access shaft with of a mobile crane. From the bottom of the shaft an overhead crane in the machine gallery takes the TG-unit to the turbine chamber where it will be mounted and connected. The pressure cover can be locked and the TG-unit can be put into operation.

In case of dismantling, the turbine chamber has to be locked with the intake gate and draft tube gate and dewatered. The pressure cover can be unbolt and removed with the lifting gear. After the dismantling of the TG-unit it can be lifted and moved to the access shaft with the lifting gear where it can be raised with a mobile crane located outside of the operation building.

Air bladder operated spillway gates are attached at the top of the weir sill. The spillway gate consists of a steel made skin plate with stiffening ribs. The skin plate is supported by several chambers of fibre reinforced rubber filled and operated with compressed air. By changing the pressure of the chambers the position of the spillway gate can be moved and the discharge can be controlled.

Number of units:	12
Runner diameter:	1,320 mm
Head:	3 m – 5 m
Design discharge	
(per unit):	11 m³/s
Total discharge	
(turbines only):	132 m³/s
Output per unit:	545.7 kW
Total output:	4.75 MW
Speed:	336.7 rpm
Average yearly produc-	
tion	24.6 GWh



Fig. 17: Technical Data of the HPP Nussdorf Données techniques de la centrale hydroélectrique de Nussdorf



The lateral seal of the spillway gate is carried out at the side panels which are aligned at the cheeks of the weir. By heating the stainless side panels and air injection at the skin plate of the gate ice-formation is prevented.

For trash drawn into the Danube Channel a trash racking concept derived from the existing concept was elaborated. The power plant will be equipped with a trash rack and underwater screen cleaning machines.

#### 4.3. Cost and Feasibility Coûts et faisabilité

The main criteria for the decision to build the power plant were the profitability and the feasibility of the project. During the feasibility study in 2002 the technical feasibility was checked and the total cost of erection was estimated to be  $\in$  15.0 million. The profitability of the project was determined using the discounting cash flow method taking into account the erection costs, costs of operation and maintenance as well as the revenues from the power production.

The yearly power production and revenues were calculated from monthly duration curves under consideration of the operation rules for weir and ship lock Nussdorf. As the minimum flow of 70 m<sup>3</sup>/s is guaranteed throughout the whole year the plant utilization is ensured most of the time.

#### 4.4. Phases of Implementation Phases de construction

The construction of HPP Nussdorf will be carried out by the Consortium Nussdorf in four main construction phases.

The first phase took place from January to end of March 2004. The excavation pit within the stilling basin was made by closing and sealing the weirs upstream and by installing pillars and stop logs downstream. During this period the excavation of concrete as well as an investigation of the existing structure was performed.

The access shaft and the operating building will be erected in the second phase from April to October 2004. The construction of the weir sill as well as the mounting of the assembling of the spillway gate and the trash racks with cleaning machines will be performed in the third phase from November 2004 to March 2005. At the same time the mechanical, electrical and controlling equipment will be installed in the operation building, as the weir has to operate after flooding the excavation pit. In fact this will be the most critical phase during implementation.

During the fourth period the mounting of the TG-units as well as the initial operation and test run will take place. The activities of the fourth phase as well as the commissioning are scheduled for spring/ summer 2005.

#### 5. Future Hydro Development Développement futur de l'hydroélectricité

Matrix technology is a new concept of hydraulic energy generation, which has been developed by an American engineer in 1983 and is still further improved by VA TECH HYDRO, which combines the advantages of proven technology and low cost installation integrated into existing dam structures and weirs. The trademarked HYDROMATRIX® technology enables customers to tap the unused hydropower potential of numerous rivers by using the existing civil structures installed on these rivers to develop a valuable renewable energy resource.

VA TECH HYDRO has recently completed the development process for another important refinement to the HYDROMATRIX<sup>®</sup> technology – the Straflo-Matrix<sup>™</sup>. The unique feature of this system is the innovative integrated turbine runner-generator rotor design, where the outer edge of the turbine blade supports the generator rotor – both turn under flow as a single unit

This configuration has significantly reduced physical dimensions in the direction of flow, allowing for applications where space is limited. It can be built into existing weirs or irrigation dams with limited space, especially if the controlling dimensions are in the plane of the turbine axis. The Straflo-Matrix<sup>™</sup> turbine is perfectly suited for the development of hydropower without interference with natural conditions and the environment.

#### 5.1. Existing Hydraulic Structures Ouvrages hydrauliques existants

The most important application examples for the Matrix technology are the use in existing dams without power production (navigation and irrigation dams), intake towers as well as sluice in ship locks.

#### 5.1.1. Navigation dams Barrage de navigation

Large lock & dams' navigational structures along a number of major rivers represent an ideal application opportunity for Matrix. Adding power production to these sites is in many cases profitable as soon as the technical feasibility is given.

#### 5.1.2. Irrigation dams Barrage d'irrigation

Worldwide many hydraulic structures and dams were erected for irrigation purposes. The spilling water to agricultural areas flows continuously without using the potential for energy production. In many cases this is an ideal opportunity for Matrix application.

The first large HYDROMATRIX<sup>®</sup> power plant is being built in Sudan at the White Nile, about 40 km south of the capital Khartoum <u>Fig. 19</u>. The Jebel Aulia dam was built in 1933 - 1937 and is used for irrigation purposes and flood control.



<u>Fig. 19</u>: The first 10 units together with the new portal crane at Jebel Aulia/ Sudan Les dix premières unités avec la grue à portique à Jebel Aulia au Soudan

Forty of the fifty gates of the Jebel Aulia Dam will be equipped with HYDROMATRIX<sup>©</sup> modules; the capacity of the plant is 30.4 MW. The power plant consists of 80 TG-units installed in 40 modules by pairs. Currently the first twenty units are connected to the grid and operate as expected.

#### 5.1.3. Intake towers Prise d'eau

Water reservoirs for drinking water or other purposes with existing intake structures are also ideal application opportunities for the use of the Matrix technology. Operating heads up to 30 m (100 ft) can be applied.

#### 5.1.4. Sluice in shiplocks Ecluses

Navigation river systems include dams and locks for ship transfer. Where an existing slot is available, a Matrix module can be installed for power generation. The turbine-generator units can be specifically designed to operate in both flow directions. Due to low operating heads feasibility has to be checked thoroughly.

#### 5.2. Small Run-of-River Development Développement de petites centrales fil de l'eau

The extremely compact design of the Straflo-Matrix<sup>™</sup> unit offers the opportunity to consider energy production in new hydraulic structures with very limited space available, resulting from legal and/ or environmental framework.

One opportunity to integrate cost-effectively Straflo-Matrix<sup>™</sup> units for power production is in over-flown transverse structures, constructed to prevent erosion of the river bed. The profitability of the power plant has to be given for the additional effort for civil works and electrical and mechanical equipment.

#### 6. Summary Résumé

Supporting the generation of electricity by means of renewable sources is a key objective of the Austrian energy policy. The country traditionally relies on hydropower which accounts for about 70% of its domestic electricity supply. In addition, environmental standards are very high and public aversion against large projects has developed to an extreme during the last two decades.

In spite of this skepticism, a remarkably innovative hydropower scheme was constructed within the boundaries of the City of Vienna in the years 1993 to 1997. The planning process was accompanied by excellent hydro experts, architects, urban planners, landscape architects and ecologist. In addition, the commencement of the works was subject to a public referendum for about two million Viennese inhabitants. 72% of the participating population was in favor of the project. "Freudenau" is now generally accepted a milestone in Austrian engineering performance and best practice in hydropower development.

As an offspring of Freudenau hydro scheme, a small hydropower plant will be constructed at an old intake structure which guards the inflow of the "Donaukanal-Tributary" into the city centre. Due to the complexity of the existing installations, it was not feasible to exploit this potential by a conventional hydro plant. Hence, a new design of hydro machinery was developed which does not require major investments for civil works and is an ideal supplement for existing structures such as dams or weirs. In the present case, the small power plant will have an installed capacity of 4.9 MW, generated by 12 units, and a mean annual energy production of about 25 GWh.

By this development of innovative hydropower plants in an urban environment, Vienna will probably be the only capital city in the world that has gained a status to accommodate a good deal of its inhabitants or households, respectively with clean hydroelectricity from the beautiful Danube River.

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### Abstract

## Innovative Hydropower Development in an Urban Environment

#### Gerhard M. Wedam

Supporting the generation of electricity by means of renewable sources is a key objective of the Austrian energy policy. The country traditionally relies on hydropower which accounts for about 70% (42.000 GWh) of the electric energy, to a bigger part through run-of-river schemes.

In the years 1993 to 1997 a remarkably innovative hydropower scheme was constructed on the Danube River, within the boundaries of the City of Vienna. The "Freudenau" multipurpose hydro development brought about a variety of benefits for urban development, such as an improvement of the local infrastructure, an enhancement of flood protection, facilities for the international river navigation, a sophisticated ground water management system and impacts for the recreational development alongside the Danube.

As an offspring of Freudenau hydro scheme, a moderate hydraulic head was generated at the more than 100 year old "Schemerl-Weir", an old intake structure which guards the inflow of the "Donaukanal-Tributary" crossing through the city centre. Due to the complexity of the existing installations, it was not feasible to exploit this potential by a conventional hydro plant. Hence, a new design of hydro machinery was developed in order to use the water flow at weirs, irrigation channels, ship locks and similar hydraulic structures: the "Ma-trixtechnology".

A Matrixturbine features a number of identical units of turbines and generators arranged in a frame that can be manufactured, pre-assembled and tested in a medium industrial workshop. It does not require major investments for civil works and is an ideal supplement for existing structures such as dams or weirs. In the present case, it will have an installed capacity of 4.9 MW, generated by 12 units, and a mean annual energy production of about 25 GWh.

## Résumé

## Le développement de la hydroélectricité inédite en milieu urbain

#### Gerhard M. Wedam

La production d'électricité d'origine hydraulique à partir des énergies renouvelables constitue un objectif central de la politique énergétique de l'Autriche.

Grâce à un contexte hydraulique favorable, l'hydroélectricité est "tradition" et le pays dispose de grandes installations hydroélectriques qui couvrent environ 70 % de la production d'électricité (42.000 GWh) en majeure partie en provenance de centrales au fil de l'eau.

Une nouvelle centrale hydraulique unique en son genre a été construite sur le Danube dans l'agglomération viennoise entre 1993 et 1997. La centrale « Freudenau » est un ouvrage hydraulique multifonctionnel dont les avantages sont nombreux sur le plan de l'aménagement du territoire de la commune : amélioration de l'infrastructure locale et de la protection contre les crues, aménagements pour la navigation fluviale internationale, un système complexe de gestion de la nappe d'eau souterraine, aménagement d'un parc de loisir le long des berges.

Un des aspects secondaires lié à la centrale Freudenau constitue l'apparition d'une terrasse à la hauteur de l'écluse centenaire "Schemerl" à l'entrée du canal du Danube traversant l'agglomération. Etant donné les conditions difficiles, les techniques conventionnelles n'avaient jusqu'alors pas permis de mettre à profit ce potentiel. Le développement d'une nouvelle technologie appelée « Matrixtechnologie » permet désormais de générer de l'énergie à partir des débits disponibles au niveau des barrages, canaux d'irrigation, écluses et autres installations.

Une « Matrixturbine » est constituée de plusieurs petites turbines et alternateurs d'un même type constituant une unité au sein d'un chassis. La construction, le montage et les essais peuvent être réalisés dans les ateliers d'une entreprise industrielle de taille moyenne. Cette turbine est particulièrement appropriée aux installations hydroélectriques existantes, tels les barrages et barrages mobiles, étant donné qu'elles ne nécessitent généralement pas de travaux de construction importants.

La petite centrale hydraulique présentée disposera d'une puissance installée d'environ 4,9 MW produite à partir de 12 unités turbine-alternateur et d'une productibilité moyenne de 25 GWh.