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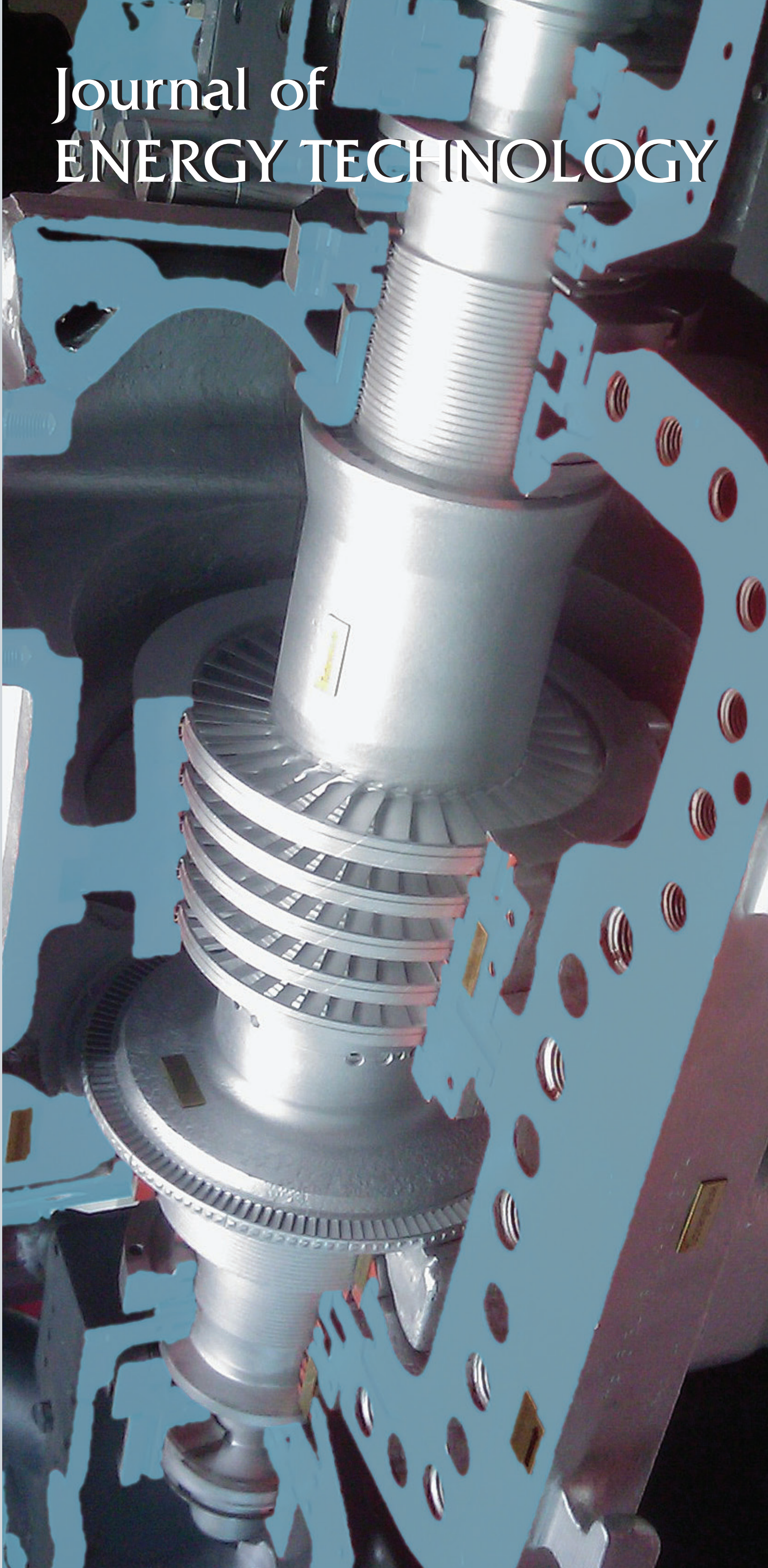
# Journal of ENERGY TECHNOLOGY



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# Journal of
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## *Ali je že napočil čas za nov korak v energetiki?*

Zadnja umetno izzvana ekonomska (monetarna?) svetovna kriza je dobila nove odseve predvsem na družbenih, socialnih, kulturnih področjih in konec koncev tudi na energetskem področju.

Predsedniki vlad ne najdejo poti, gospodarstveniki tarnajo in tavajo v zaprtem krogu države, kultura se izgublja (ali utaplja?), apatija ljudi je vse večja. Seveda ni nič čudnega, da se vse to reflektira tudi na našem energetskem področju. Nič čudnega, ko pa vsak dan iz medijev slišimo samo banalne novice, kako je kdo kaj ukradel, kako si je človek sodil sam, ker je storil moralni prekršek, mediji pa so z največjim veseljem neusmiljeno drezali vanj… In seveda o našem »Slovenskem zlatem dimniku«, ki je presegel vse meje razumnosti, ali če želite človečnosti, ko na eni strani nekateri nimajo kaj za v usta, na drugi pa se nekateri sprenevedajo, od kod jim poldrugi milijon na bančnem kontu ali v sefu? Da, naš zlati dimnik je požrl enormna sredstva, ki bi jih lahko bistveno bolj preudarno naložili v druge, tehnološko bolj napredne veje energetike in bi bili tako lahko vzor za napredno družbo, ki odpira nov korak v energetiki s tem, da se že končno enkrat oddalji od »ogljikovega« lobija in pretrga dosedanjo odvisnost od le-tega. Ne, žal tudi pri nas še vedno zmaguje ta lobi. Še vedno smo »jahajoča družba«, v kateri šteje le tisti, ki je najvišji v jahajoči piramidi, pravzaprav enako, kot v dvajsetih letih zgodnjega kapitalizma v Združenih državah Amerike. Kot noji še zmeraj rinemo z glavo v pesek in si zatiskamo oči, zavedajoč se dejstva, da je denarja, hrane in energije na svetu dovolj za vse, le porazdelitev šepa. To je že daleč nazaj ugotovil naš Nikola Tesla, pa ga še danes ne želimo (nočemo) razumeti. Nikola je razumel, da vsa energija prihaja od našega sonca, ki ne more biti zasebno (hvala bogu). Res je da še danes koristimo najbolj primitivne oblike (premog, nafta, plin, …), za katere pa smo si enotni (vsaj upam tako), da trajnostno gledano onesnažujejo naš svet, ki ga imamo samo »v najemu« od naših vnukov. A ni že skrajni čas, da se zamislimo kaj bodo naši vnuki mislili o nas?

Morda pa z novo vlado vendarle napravimo korak naprej tudi na energetskem področju Slovenije.

Andrej PREDIN

## *Is it already time for a new direction in the energy sector?*

The recent artificially induced economic (monetary?) global crisis has given rise to new reflections, especially on the social and cultural fields as well as, ultimately, on the energy field.

Politicians cannot find the way out, economists complain and wander about seeking a state-based solution, culture is being lost (or drowning), and the apathy of people is increasing; consequently, it is not surprising that all this is also reflected in the energy field, especially considering that we daily hear from the media just predictable news about how someone stole something, how someone should be judged because of an alleged moral offense (and the media have the greatest pleasure in reporting this) and of course about our 'Slovenian golden chimney', which has exceeded all limits of reasonableness, or if you want also all limits of humanity. On one hand, some do not have anything to eat, when on the other, some pretend that they do not know where the half million in their bank account or safe came from. Yes, our golden chimney has consumed enormous resources that could be much better invested in the other, more technologically advanced branches of electric energy production. If we do so, we can be an excellent example of an advanced society, which opens new directions in the energy field. This would finally be the path away from the so-called carbon lobby would cut society's the dependence on it. Unfortunately, the carbon lobby is still winning in our country. We are still 'pyramid society' in which only those who are at the highest level have rights. We still live like in the early years of capitalism in the United States. Like ostriches still putting their head in the sand, we shut our eyes, mindful of the fact that the money, food and energy in the world are enough for all, but only distribution has failed. Nikola Tesla knew this to be true in his time, but we still do not want to accept it, or want to understand it. Tesla understood that all of our energy comes from the sun, which cannot be privatized (thank goodness). It remains true that we use more primitive forms of energy sources (coal, oil, gas, etc.) because of its simple use (via simple technology). However, I do hope that we all know that these technologies have a serious impact on the environment that we have only rented from of our grandchildren. Is it not already the right time to imagine what will our grandchildren think about us?

Perhaps we will have success with the new Slovenian government and also step forward in the field of energy.

Andrej PREDIN

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# NUMERICAL ANALYSIS OF AN AXIAL FLOW FAN: ANSYS VS SOLIDWORKS

# NUMERIČNA ANALIZA AKSIALNEGA VENTILATORJA: ANSYS IN SOLIDWORKS

Igor Ščuri [ℜ], Marko Pezdevšek, Igor Spaseski, Matej Fike, Gorazd Hren

**Keywords:** numerical analysis, axial fan, CFD, Ansys CFX, SolidWorks

## Abstract

Axial flow fans are designed to operate in stable parts of the characteristic curves for the axial fan. However, it is possible that the operation regime becomes unstable due to changing conditions, resulting in a decrease of the fan's operational characteristics. In this article, a simulation is focused on the stable part of characteristic curves for the axial fan at various mass flow rates, which were acquired with numerical simulation software packages: Ansys CFX and SolidWorks Flow Simulation. The analyses were performed on designed structured meshes with similar numbers of elements, for different mass flow rates. In order to validate the numerically obtained results from both software packages, we compared them to experimental values from a reliable source.

## Povzetek

Aksialni ventilatorji so zasnovani tako, da delujejo v stabilnem področju dušilne krivulje. Določene omejitve lahko povzročijo, da delovanje ventilatorja preide iz stabilnega v nestabilno področje dušilne krivulje. Slednje negativno vplivajo na karakteristike ventilatorja. V članku so predstavljeni rezultati numerične analize dušilne krivulje aksialnega ventilatorja s poudarkom na stabilni del pri različnih masnih pretokih. Za izvedbo numeričnih simulacij sta bila uporabljena programska paketa Ansys CFX ter SolidWorks Flow Simulation. Analiza je bila izvedena s strukturirano mrežo za več masnih pretokov. Z namenom, da ovrednotimo rezultate numeričnih simulacij, smo le te primerjali z eksperimentalno pridobljenimi vrednostmi iz literature.

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# 1 INTRODUCTION

A fan is typically a mechanical device that causes the movement of air, vapour or other gases in a given system. The basic purpose of the fan is to move a mass with a desired velocity. In order to achieve this objective, there is a slight increase of pressure across the fan rotor. However, the main aim remains to move the mass without any appreciable increase in pressure.

Axial flow fans are mainly used for ventilating and air conditioning applications for buildings, mines, vehicles, underground transportation systems, etc. Each application requires a different type of fan. Within a system, particular fans are more appropriate than others in terms of capacity and pressure increase capabilities. In this sense, axial flow fans are generally categorized into four types: propeller fans, tube-axial fans, vane axial fans, and two-stage axial fans, [1].

Axial flow fans are the type for which the fluid flow is predominantly axial, i.e. parallel to the axis of rotation. Axial flow fans usually use air as the working fluid, which operates in an incompressible range, at low speeds and moderate pressures. The flow is treated as axial, with no radial component. The pressure rises with the tangential velocity component increasing, due to the rotation of the impeller and an aerodynamic diffusion process afterwards, [2].

The airflow around the blades profile affects the general shape of the characteristic curve. Furthermore, the airflow through the axial fan causes changes in the angle of attack and the velocity of the airflow around the blades. Due to the aforementioned effects, the axial fan operates in a stable or an unstable part of the characteristic curve, [3].

Axial fans are designed to operate in stable parts of characteristic curve. However, due to spatial or other limitations, it is possible that the fan operation regime becomes unstable, resulting in a decreasing of the fan's operational characteristics. This paper presents a numerical analysis resulting in the characteristic curve of the axial fan with a focus on the stable operating regime.

# 2 GOAL DEFINITIONS

In order to compare different numerical software packages, we decided to perform numerical analyses and compare the computed results to existing experimental data of characteristic curves, [3]. The comparison was performed at different mass flow rates, declining from 0.7 kg/s to 0.4 kg/s with a step of 0.05 kg/s and from 0.45 kg/s to 0.40 kg/s with a step of 0.01 kg/s. In addition, the comparison was also made at mass flow rate of 0.475 kg/s.

Steady-state simulations were made with Ansys CFX 15.0 and SolidWorks Flow Simulation (SWFS) 2014 software packages in order to obtain the characteristic curve of the axial fan. We have to emphasize the differences in the purposes of the software packages and their limitations. Ansys CFX is a well-known commercial standalone numerical software for numerical analyses, and SolidWorks Flow Simulation is part of a CAD (computer-aided design) package. We attempted to create corresponding meshes and boundary conditions in order to compare the results of analyses, the definitions of meshes, and the user-friendliness of software.

# 3 NUMERICAL MODEL

In order to obtain reliable results, we created meshes with a comparable number of linear elements in both software packages. The axial fan model was simulated assuming steady-state conditions using various Reynolds-averaged Navier-Stokes (RANS) turbulence models. SWFS provides only the $k$-$\varepsilon$ turbulence model, while Ansys CFX offers various options. We performed analyses with the $k$-$\varepsilon$ turbulence model and the shear stress transport (SST) turbulence model in Ansys CFX.

## 3.1 Geometry

The geometry of the axial fan used in the experimental measurements is highly complex. The fan rotor contained small parts, e.g. screws and mounting brackets, which are difficult to survey with the computational mesh. Therefore, the small parts that we assume are not necessary for simulation results have been suppressed from the numerical model, thereby reducing the number of elements of the mesh, and decreasing the required computer resources and time for solving governing equations.

The three-dimensional geometry of the axial fan was modelled in SolidWorks. The numerical model of the axial fan consists of three main parts: inner hub, axial fan rotor with blades and outer tube. The inner hub was divided into two parts. The hub ahead of the axial fan rotor was 1000 mm long and behind it was 2000 mm long. The diameter of the hub is constant with the length of the whole model. With a diameter of 285 mm, the axial fan rotor includes ten aerodynamic blades. The blades have a NACA 6508 profile with a chord length of 80 mm. The blade shape is constant in the radial direction of the blade. The blade angle, i.e. the angle between the chord of the blade and the circumferential direction of the fan, is 45°. The blades have been designed with 2.5 mm as the gap between the top of the blade and outer tube. Therefore, the gap between the top of the blade and the outer tube was constant through the entire length of the model. The geometry of the fan is presented in Figure 1.

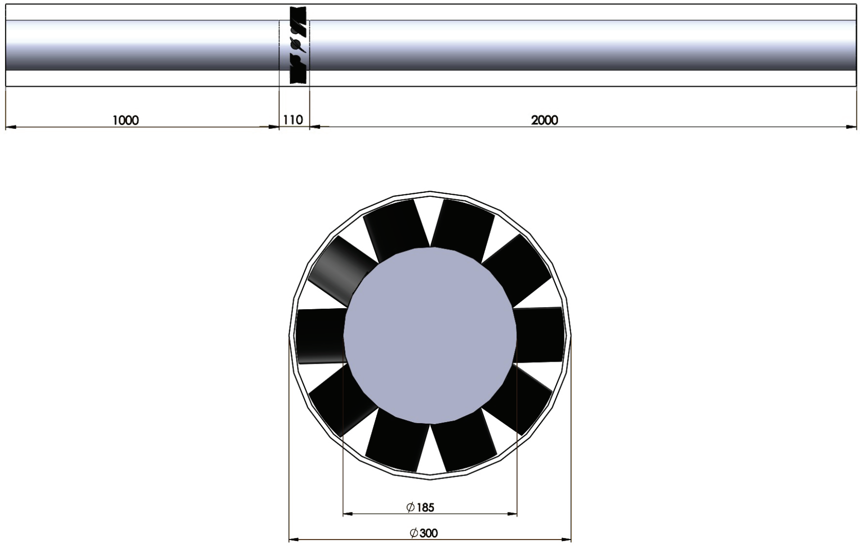



***Figure 1:*** *Axial fan geometry.*

## 3.2 Mesh creation

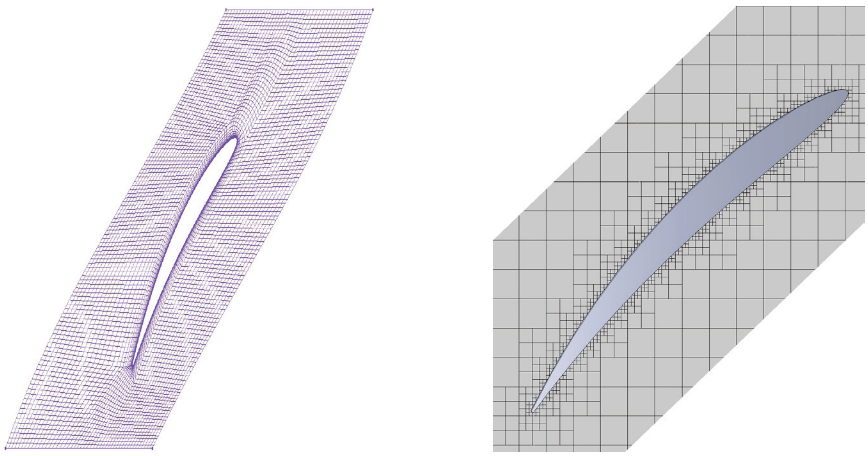
In CFD, the numerical mesh has two basic functions: defining the geometry and the discretization of computational domain. The geometry of the numerical mesh has to fulfil the geometry to the greatest extent possible. The complexity of the modelled object affects the final mesh size and, consequently, the required design time. The amount of computer resources for the implementation of the numerical simulations is directly proportionate to the mesh resolution. The accuracy for solving the discrete equations depends on the number of discrete elements and the nodes of the mesh. Generally, a numerical solution becomes more accurate when a mesh with greater resolution is used. Furthermore, a mesh with a higher density is commonly used in areas where high spatial and temporal gradients of critical quantities accrue. In numerical simulations, we tended to optimise mesh size for greater accuracy of results, which are usually limited by available computer resources.

Structural computational meshes were designed with a pre-processor ICEM CFD 15.0 for the Ansys CFX software, with which we designed separate meshes for the domain ahead of the rotor, behind the rotor and the rotor itself. Once the three meshes were created, they were merged in Ansys CFX to form a single mesh, which represents the full computational domain. In SWFS, the mesh was created with the built-in mesh manager. Table 1 shows comparable number of elements in both software packages.

***Table 1:*** *Mesh data*

| Ansys CFX<br>Number of elements | SWFS<br>Number of elements |
|---|---|
| 3,030,110 | 2,929,807 |

Figure 2, shows a part of the structural mesh created in ICEM CFD and SolidWorks. The resolution of the mesh is greater in regions where greater computational accuracy is needed, e.g. the region close to the blade. The close-ups of the mesh are shown, which clearly represent a different type of mesh creation. Typical structured meshes from Ansys and the use of a Cartesian-based mesh generation in SolidWorks, [4], are presented.



a) b)

***Figure 2:*** *Numerical mesh designed with a) ICEM CFD software and b) SWFS software in close-up view.*

## 3.3 Boundary conditions and convergence criteria

Boundary conditions fulfil an important role in all simulations because they govern computational stability and numerical convergence. The initial conditions of the simulation are also specified at these boundaries.

The boundary conditions inlet and outlet were defined in both software packages. Different mass flow values were defined for the inlet boundary condition, and the static pressure of 100 kPa was applied to the outlet boundary condition. The mass flow inlet boundary condition requires the specification of the turbulent inlet flow conditions, so the turbulence intensity was set to 1.5% and the turbulence length to 0.01 m. The air density was set to 1.185 kg/m³ and the dynamic viscosity to $1.79 \cdot 10^{-5}$ kg/ms. The axial fan rotor's angular velocity was set to 1440 rpm, [3].

For SWFS, the outer tube and inner hub surfaces were defined as a real wall and then selected to be stationary (stator). For the computation in Ansys CFX, the domains ahead and behind the rotor were defined as stationary domains. The rotor was defined as a rotating domain with the abovementioned angular velocity. In the stationary domain, the top and bottom surfaces were defined as walls. In the rotational domain, the inner surface of the blade and the bottom surface were defined as walls. The boundary condition stage was applied to the surfaces between the rotating and stationary domains, and the sides were defined as rotational periodicity.

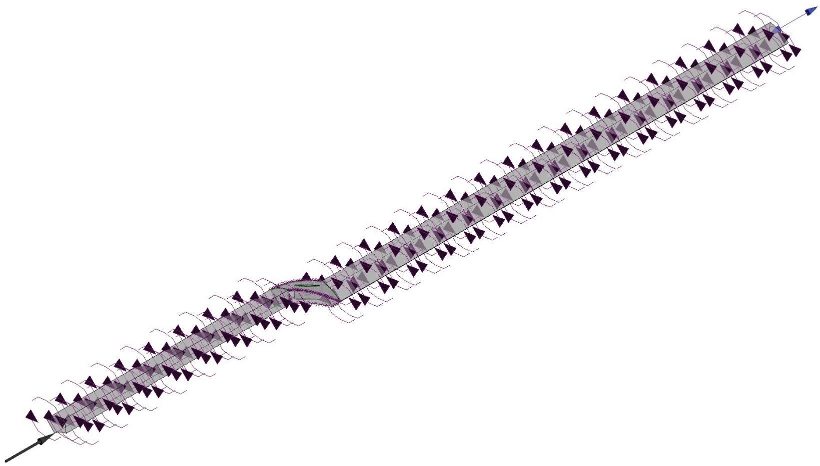


***Figure 3:*** *Boundary conditions defined in Ansys CFX.*

To satisfy the convergence criteria, all the RMS (root mean square) leftovers from solving equations must be under $1 \cdot 10^{-5}$. We also set number of maximum iterations to 500 and used automatic timescale control. Both software packages have an automatic system for stopping the analysis when it reaches predefined convergence criteria.

# 4 RESULTS

## 4.1 Characteristic curve

The computed results of the axial fan characteristic curves at various mass flow rates were compared to existing experimental data from [3].

The characteristic curve of the axial fan is defined with the relationship of integral parameters, which are presented by dimensionless numbers. The flow number (coefficient) φ is calculated with the equation:

$$\varphi = \frac{4 \cdot q_v}{\pi \cdot D^2 \cdot u}, \tag{4.1}$$

where:

$q_v$ - mass flow rate;

$D$ - rotor diameter;

$u$ - tangential velocity.

The pressure number (coefficient) ψ is defined with the equation:

$$\psi = \frac{2 \cdot \Delta p_s}{\rho \cdot u^2}, \qquad (4.2)$$

where:

$\Delta p_s$ - simulated (measured) static pressure increment;

$\rho$ - air density;

$u$ - tangential velocity.

Figure 4 shows the comparison between experimental data and numerical analysis results for characteristic curves at different mass flow rates.

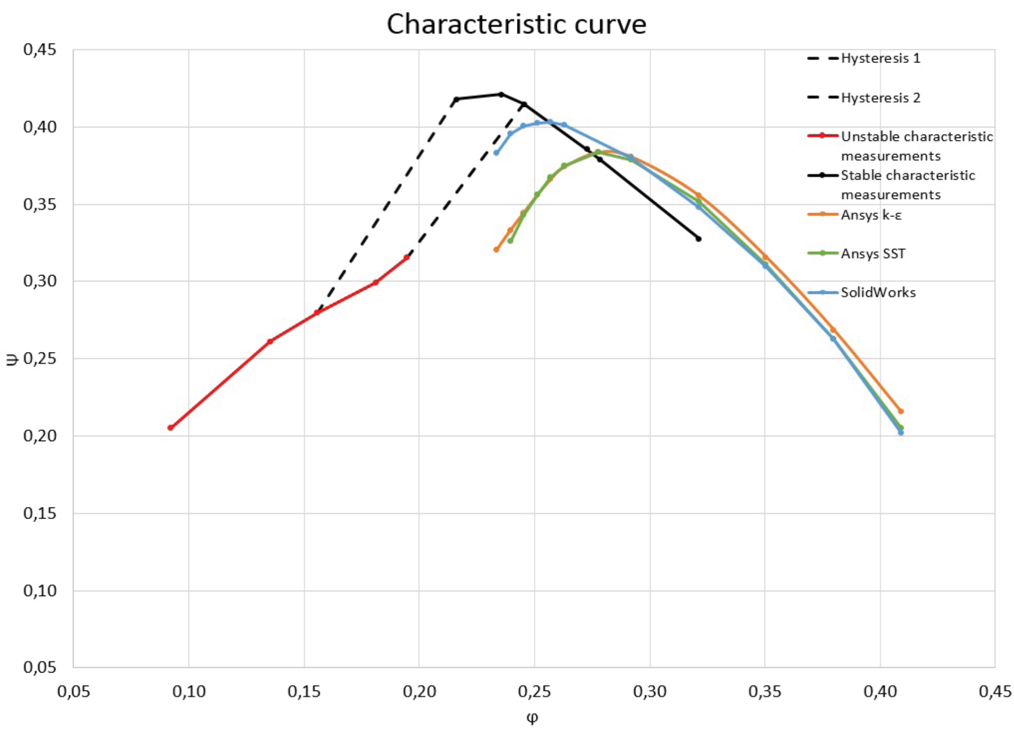



***Figure 4:*** *Comparison between experimental data and the data obtained from simulation software packages of the characteristic curves at different mass flow rates.*

## 4.2 Computation time

Table 2 shows the average computational times needed for computing the characteristic curve parameters. Computational times in Ansys CFX software using the *k-ε* turbulence model were slightly longer than those using the SST model when one tenth of the axial fan model was simulated. Furthermore, the SolidWorks software took about twice as much time to finish the simulation on the entire axial fan model.

***Table 2:*** *Average computational times needed for computing characteristic curve parameters*

| Simulated model (ca. 3,000,000 elements) | Computational time [hh]:[mm]:[ss] | | |
|---|---|---|---|
| | SolidWorks | Ansys CFX *k-ε* model | Ansys CFX SST model |
| 1/10 of the axial fan model | / | 0:40:03 | 0:38:52 |
| Whole axial fan model | 10:11:42 | 6:40:30 | 6:28:40 |

# 5 CONCLUSIONS

Simulations of the characteristic curve parameters for various mass flow rates were conducted in order to compare the results from different software packages and then validate them with experimental data.

In Ansys CFX, at mass flow rates lower than 0.4 kg/s, convergence was found to be problematic. Therefore, the comparison between the software was made at mass flow rates ranging from 0.7 kg/s to 0.4 kg/s.

Results obtained from SolidWorks correlate quite well with the experimental results within the normal (stable) operating range of the axial fan. Generally, SolidWorks produced, in our case, better results than Ansys CFX, when using both turbulence models. The correlation between the numerical and experimental values for both turbulence models in Ansys CFX was found to be adequate.

Computational times in Ansys CFX software using *k-ε* turbulence model were slightly longer than those using the SST model when one-tenth of the domain was simulated. With the lack of a rotating periodicy feature in SolidWorks, the results could not be obtained and consequently compared. In this case, when the whole axial fan model was simulated, SolidWorks software took about twice as much time for performing the simulation.

Based on the computed results and computational times, Ansys CFX would be the better pick for the example used in this paper, regardless of the turbulence model. Nevertheless, SolidWorks' computed results were found to be sufficient, but the lack of rotational periodicy means that a large amount of computational resources and time was required to compute the results.

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# LARGE HYDRO POWER PLANTS IN SLOVENIA

# VELIKE HIDROELEKTRARNE V SLOVENIJI

Ivana Tršelič[ℜ]

**Keywords:** large hydro power plant, water energy, water pollution

## Abstract

Electricity distribution started in Slovenia with hydro power. The first real use for electricity was street lighting, industry, and workshops. With the evolution and expansion of such usage, power lines had to be built. In Slovenia, large hydro power plants on three Slovenian rivers (Drava, Sava, Soča) account for almost one third of the electricity produced in Slovenia. Rivers have limited amounts of water, although there is a large amount of annual precipitation; the problem is that the water is not equally distributed. Slovenia has dry and rainy periods, marked by drought and flooding. With developments and investments in hydro power plants, the efficiency of turbines is being successfully improved; however, for better exploitation of water energy, building new power plants is required.

## Povzetek

Slovensko elektrogospodarstvo je pričelo svoj razvoj z izkoriščanjem vodne energije. Prvi porabnik električne energije je bila javna razsvetljava mest, kasneje industrija in manjši domači porabniki, obrtniki. Vzporedno z razvojem elektrogospodarstva je potekala izgradnja daljnovodov. V Sloveniji večje hidroelektrarne katere izkoriščajo vodno energijo treh večjih slovenskih rek: Dravo, Savo in Sočo priskrbijo skoraj tretjino proizvedene elektrike v Sloveniji. Omejene so s količino vode, katere je v Sloveniji dovolj, le da je neenakomerno porazdeljena preko celega leta, tako po sušnem poletnem obdobju sledi jesensko poplavno obdobje, ki prav tako ovira konstantno delovanje hidroelektrarn. Z dogradnjo in obnovami hidroelektrarn je slovensko hidroelektro gospodarstvo uspešno

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izboljšalo izkoristke turbin in nekaterim hidroelektrarnam povečalo pretok, tako da so izboljšave na tem področju dovolj omejene, da je potrebno razmišljati dalje in iskati možnosti za izgradnjo novih hidroelektrarn.

## 1 INTRODUCTION

The current condition of the economics of large hydro power plants in Slovenia is the subject of this review.

Slovenian electric power distribution started its development at the end of the 19$^{th}$ century. During the time of Austro-Hungarian Empire, the Slovenian region was geologically and topographically explored. The first hydro power plants were planned for the Styrian region.

World War One hindered development. Although the economy was in poor shape, the development and planning of new hydro power plants continued, the electric power system grew, and new consumers were sought.

At present, the situation is reversed; the demand of consumers is greater than the amount electric energy produced. Old hydro power plants have been rebuilt, and new modern hydro power plants have been and are being build. The control and monitoring of hydro power plants are automatic and sophisticated. The system greatly depends on the amount of precipitation because Slovenia has no conventional hydro power station with large natural reservoirs, but only run-of-the-river electricity production systems. Therefore, electricity production is strongly influenced by hydrologic conditions.

The Sava River basin is a torrent type, in which large fluctuations of the river current occurs, thus influencing the electricity production, [1].

## 2 ENERGY STORED IN WATER

Water is the most important renewable energy source: 21.6% of electric energy produced in the world comes from exploiting energy from water, [2].

Energy stored in water is actually a gravitational force, seen as falling and flowing water. A hydro power plant is where energy conversion from potential to kinetic to mechanical work into electric energy happens. This conversion should not have an environmental impact, as the entire infrastructure of the hydro power plant brings beneficial and adverse changes to the environment in the immediate area of the hydro power plant.

Building a hydro power plant influences the environment in different ways, affecting the landscape and the surface of the river bed. It also influences the characteristics of water flow in the river and around it, [2].

Adverse influences of hydropower plants are observed via analysis of river sediment, which reveals high concentrations of toxic elements in reservoirs, such as sulphur compounds in toxic metals (lead, potassium) and eutrophication substances, such as compounds of phosphorus and nitrogen. Therefore, dropped silt is evaluated as waste, with high amounts of harmful substances [3]. Hydropower plants also endanger fauna, because the oxygen level is decreased, and fish are inevitably suffocated.

The beneficial influence of hydropower plants is in their low operational costs and long periods of operation. Hydropower plant technology is considered to be a green technology. It is reliable and stable when connected to the electrical power grid, [2].

As an environmental friendly technology, hydropower is implemented according to energy and environmental policies.

The main types of hydro power plants are, [2]:

1. Run-of-the-river HPP, with which a river flow with a relatively low drop is exploited. The river has a dam, but no large reservoir of water is created.
2. Conventional HPP of dammed water with large drop and lower river flow. Water is accumulated with dams or flooded valleys and canyons.
3. Combinations of run-of-the-river and dam hydro power plant are built in a chain, in which the first one has a reservoir.

Building a hydro power plant requires a significant intervention in the environment, as it influences farming, forestry, groundwater, the quality of the water, natural river affluent, and the economy (fishing, tourism, and infrastructure).

# 3 WATER IN SLOVENIA

Slovenia is water-rich country, although the water supply is not time and space consistent, [5]. An analysis data of water balance from 1971 to 2000 shows that more than half of the average precipitation (1579 mm) contributes to river flow (862 mm), [4].

Large amounts of precipitation, especially in the western and northern parts of Slovenia, classifies the country among water-rich countries on international scales. Furthermore, water is restored seasonally. According to evaluations, Slovenia has one of the largest amounts of water per capita in Europe. Water deficits are observed in the regions of Kras, Suha and Bela krajina, Obsotelj, Haloze, Slovenske Gorice and the northern part of Prekmurje. Water resources are reflections of climatic conditions, hydrology, relief and geological conditions. Inequalities of those factors determines the existence of different water regimes, [5].

Slovenia is divided into two water regions: that of the Danube River, and that the Adriatic Sea. The Soča River is part of the latter and is 95 km long. In the Danube water region there are the Sava, Drava and Mura rivers. The Sava is Slovenia's longest river; from its source at Sava Dolinka in Zelenci to the Croatian border it runs 221 km. The Drava River has 142 km in Slovenia, and the Mura 95 km, flowing directly on the border with Austria for 65 km.

Taking the river flow into account, the Drava is Slovenia's most water-rich river; after its confluence with Pesnica, the Drava's flow exceeds 320 $m^3/s$. Apart from the Sava and Mura, other rivers have significantly lower flow because of minor river basins and characteristics of water accumulation outskirts, [5].

# 4 HYDRO POWER IN SLOVENIA

## 4.1 Development of electricity distribution worldwide and in Slovenia

The development of electricity distribution started with the invention of the light bulb. The electric wire was first presented in Paris in 1881: a light bulb with a charcoal filament. From that year onward, electricity distribution developed into one of the strongest branches of the economy, [6].

Cities built small local power plants for electric lighting for individual facilities and factories, or for street lighting. At the beginning, there was a direct current with voltage of 65 V, then 110 V and later 220 V. In the second phase of electricity distribution, provincial lighting developed with alternating current. Power plants were placed directly by the energy source, i.e. by the water, by the coal mine.

In Slovenia, the first power plant was a hydro power plant built in Škofja Loka in 1894. The hat factory Šešir installed a water turbine in 1889 for production purposes. In 1894, a generator was implanted; it produced direct current with a voltage of 110 V and with 15 kW of power, [7]. In addition to production, the Šešir factory started to sell the electricity for street lighting in Škofja Loka, [8].

In Ljubljana, the first power plant started to operate in 1898. In 1914, there were 17 locally operated power plants in Slovenia (not counting the Primorska region), with electric power of 2500 kW.

The Završnica hydroelectric power plant was the first Slovenian public power plant. The construction of the plant occurred during World War I. And all obstacles aside, it was activated in February 1915, illuminating the streets of Radovljica and Bled.

A descriptions of that special day states: "The hydropower plant on Završnica started to operate! For our economy this is very important. Circumstances do not allow special celebration", [9], and "We can see long desired electrical street lighting in Bled. Only now is Bled what it should have been a long time ago. The illumination is beautiful. Around the Lake of Bled crown of lights – it is magical", [10].

The Završnica hydropower plant operated until 2005, after which it became a technical and historical monument. Its part in producing electricity was overtaken by Moste HPP.

In 1912, in Styria, preliminary planning of the Fala hydro power plant on the Drava River started. World War I caused a delay, and Fala HPP started to operate in 1918. It was intended to supply industry in upper Styria (sl: Štajerska) with electricity. When World War I ended, Yugoslavia was entitled to Fala HPP, although the investment had come from elsewhere, [11].

After World War I, electricity distribution greatly expanded, with industrial power plants being build parallel to public power plants.

World War II influenced the development of economy electric energy production. When the Primorska region joined Yugoslavia, more hydro power plants on Soča River were obtained: Doblar and Plave, [6].

After the end of the war, a systematization of electricity distribution began. A state power plant company was founded. This company joined public and industrial power plants. Six main energy regions were founded: Drava, Sava, Soča, Trbovlje, Rajhenburg, Velenje, [6].

Slovenian large hydropower plants are follows:

- SENG - Slovensko elektrogospodarstvo Nova Gorica (Hydro power plants: Doblar 1 in 2, Plave 1 in 2, Solkan, Avče)
- SEL - Savske elektrarne Ljubljana (Moste, Mavčiče, Medvode, Vrhovo)
- HESS - Hidroelektrarne na spodnji Savi (Boštanj, Blanca, Brežice, Krško)
- DEM - Dravske elektrarne Maribor (Dravograd, Vuzenica, Vuhred, Ožbolt, Fala, Mariborski Otok, Zlatoličje, Formin)

In the last quarter of 20$^{th}$ century, the number of small hydro power plants increased from 12 to 36. In same period, the production of electricity from hydro power plants doubled, [12].

With the expansion of economy and the erection of new power lines, the consumption of electricity increased and electricity distribution expanded. Consumption levels continue to increase (with a minor decrease following the most recent recession).

## 4.2 Hydro power plants of river Sava – upper course

### 4.2.1 HPP Moste

Hydro power plant Moste started operating in 1952. It is a hydropower plant with accumulation planned for production of electricity in peak demand. Three generators with Francis water turbines have been installed. The flow is 28.5 $m^3/s$.

In 1977, Moste HPP built a forth generator and successfully realised affiliation with Završnica HPP. The system was planned to pump the water into the upper reservoir of Završnica and use it when demand exceeds the production of electricity. Unfortunately, this system was never realised because of water pollution. The generator was reconstructed in 1999. Between 2008 and 2010, a thorough reconstruction of the entire plant took place. The system produces 21 MW of power, [13].

### 4.2.2 HPP Mavčiče

Hydro power plant Mavčiče is a run-of-the-river hydroelectric power station, with a construction height of 40 m. With two Kaplan turbines and 260 $m^3/s$ of flow, the system produces 38 MW of power. Operations began in 1987. Reconstruction started in 2011 with renovation of the equipment and exterior switchyard, [14].

### 4.2.3 HPP Medvode

Hydro power plant Medvode lies above the confluence of the Sava and Sora Rivers. The dam is made of concrete and makes use of the reservoir from HE Mavčiče. The first two generators started to operate in 1952, the third one in 1955. When the barriers were heightened by one meter in 1964, the power of the turbine increased by 11%. Two Kaplan turbines are able to produce 25 MW of power. In 2003 and 2004, the hydro power plant was modernised; turbines and secondary equipment were replaced, [15].

### 4.2.4 HPP Vrhovo

Vrhovo HPP is the first hydro power plant in a series on the lower river course of the Sava. Vrhovo HPP started to operate in 1993. With a concrete dam with a construction height of 27 m, the hydro power plant operates as run-of-the-river hydroelectric station, but also serves as reservoir for hydro power plants lying downriver. With three generators, Vrhovo HPP produces 34.2 MW of power, [16].

## 4.3 Hydro power plants of the Sava River - lower course

### 4.3.2 HPP Boštanj

Boštanj HPP is the second hydroelectric station and one of the six hydro power plants built on the lower course of the Sava River. It produces 36 MW, which represents 1% of the electricity produced in Slovenia. The plant started to operate in 2006, [17].

### 4.3.3 HPP Blanca

Arto-Blanca HPP is the third hydro power plant in the chain of lower course of Sava River. It produces 42 M and started to operate in 2010, [18].

### 4.3.4 HPP Krško

Krško HPP produces 42 MW. This hydro power plant is constructed as combination of accumulation and run-of-the-rive. It started to operate in June 2013.

## 4.4 Hydropower plants of the Drava River - Dravske elektrarne Maribor

The Drava River springs originates from Dobbiaco in South Tirol in Italy. Near Dravograd, it enters Slovenia and, after 133 km, it continues its flow into Croatia. Before the construction of hydro power plants, the Drava was used for transport with rafts to Danube towards the Black Sea.

### 4.4.1 HPP Dravograd

Dravograd HPP in the first hydro power plant in the chain of Drava on the territory of Slovenia. In 1944, it started to operate and it was one of the first pier-type power plants in Europe. Construction began in in 1941 during World War II. In April 1945, allied air raids caused considerable damage to the power plant. With the launch of the third unit in 1955, construction of the power plant was completed, [19].

With renovation of the generator, which started in 1994, the power of HPP increased by 26 MW. In 2010 and 2011, the 110 kV exterior switchyard was modernised. Construction a dam created a reservoir that spreads to Austria, [19].

### 4.4.2 HPP Vuzenica

Hydro power plant Vuzenica is the second in line on the Drava River. Construction started in the fall of 1947. In HE Vuzenica, the first domestically made Kaplan turbine was installed; it was produced in Litostroj. The first generator started to operate in 1953. After reconstruction in the 1990s, the power increased by 11.2 MW. It is a run-of-the river power plant with pillar construction producing 56 MW, [20].

### 4.4.3 HPP Vuhred

HE Vuhred operates in a region where the Radlje field closes into a narrow water channel. It is the first of two stages that share the available head of the section of the Drava between the Vuzenica and Fala power plants. Topographical and geological surveys performed immediately after World War II showed that two power plants could be built in this section. Construction began in 1952. The Vuhred HPP was the first plant in the former Yugoslavia that had been planned and constructed on the basis of domestic experience and equipped solely with domestic Slovenian equipment. The first two units began operations in 1956 and the third in 1958. The second phase refurbishment of the Upper Drava power plants, concluded in 2005, encompassed the replacement of the turbines and the other equipment to increase the net capacity of the power plant and flow, [21].

### 4.4.4 HPP Ožbalt

The second power plant on the section of the Drava River between Vuzenica and Fala was built between 1957 and 1960 as the twin of the Vuhred HPP upstream. The Ožbalt HPP is the fourth power plant in the Slovene section of the Drava River; construction began in 1957 and within three years two units were operating. Since the Ožbalt HPP has the same energy specifications as the Vuhred HPP, the pier type structure was also chosen. After the refurbishment of the Upper Drava power plants in the 1990s, the net capacity increased to 73.2 MW. The plant, with its increased power, annually generates 305 million kWh of electricity. The damming of the Drava River here resulted in a 12.7 km long reservoir containing 10.5 million $m^3$ of water, of which 1.4 million $m^3$ can be used for the generation of power, [22].

### 4.4.5 HPP Fala

Construction of HPP Fala started in 1913 with the first five units commissioned as early as 1918. Due to increased demands for electric power, a sixth unit was built in 1925 and then a seventh was completed in 1932. When construction of all the other power plants on the Drava River was completed, the plant's turbine discharge proved low in comparison and this led to the construction of an eight unit in 1977 using a Kaplan turbine with the capacity of 17 MW. After extensive refurbishment, the three newer units make use of the 14.6 m available head, have a net capacity of 58 MW, and can generate 260 million kWh of electricity annually, [23].

Within the dam structure complex, the old power house has been preserved as an important item of technical heritage. Its units, comprising double horizontal Francis turbines and generators on the same shaft, were closed down in stages as a result of the construction of the new powerhouse. Today, the old powerhouse is an interesting vantage point for visitors allowing them to become acquainted with both the previous and current methods of operating the power plant, [23].

### 4.4.6 HPP Mariborski otok

This pier type power plant is located just outside of Maribor in the riverbed, exploiting the energy potential of the Drava River between the Fala HPP and the island in the Drava River.

The construction of the power plant had been planned prior to the World War II, but construction only began in 1942. The war caused the construction process to be drawn out considerably, so that in May 1945 it was still only 30% completed. Despite a number of problems after the war, construction work continued and 1948 saw the commissioning of the first unit, with the second and third units beginning operation in 1953 and 1960; its construction created a 15.5 km long reservoir. The dam structure contains three turbine piers between four spillways and a left and right bank building. Each of the turbine piers contains a vertical Kaplan turbine and a generator above it. A 10 kV switchyard and an areas for two main transformers directly connected to 110 kV transmission lines leading towards the Pekre substation are located in the right bank building. Mariborski otok HPP uses the 14.2 m available head and, following its refurbishment, annually generates 270 million kWh of energy with a net capacity of 60 MW, [24].

### 4.4.7 HPP Zlatoličje

HPP Zlatoličje generates more than a fifth of all the electric power generated by Dravske Elektrarne Maribor and makes use of the energy potential of the Drava River between the cities of Maribor and Ptuj where the river turns into a flatbed. Due to its location, it has been designed as a channel-type power plant. The Zlatoličje HPP makes use of the 33 m head and, after refurbishment from 2007 to 2012, annually generates 577 GWh of electricity with a threshold capacity of 126 MW. The power plant, built between 1964 and 1969, has a supply and discharge channel separate from the riverbed, a 4.5 million $m^3$ reservoir and a dam structure in Melje near the city of Maribor, [25].

### 4.4.8 HPP Formin

As the last in the chain of power plants on the Drava River, this plant rates as the second largest in terms of electric power generated and also boasts the largest reservoir in the Slovene section of the Drava River. The power plant was completed in 1978 and, due to the natural conditions, was designed as a channel-type power plant, similar to Zlatoličje HPP. With its 29 m available head on the section between Ptuj and the national border with Croatia and with a net capacity of 116 MW, it generates 548 million kWh of electricity annually, [26].

The damming of the Drava River with a dam in Markovci resulted in the creation of the largest artificial lake in Slovenia, with a length of 7 km and a water surface of 3.46 $km^2$. It is called Ptuj Lake and it contains 17.1 million $m^3$ of water of which 4.5 million $m^3$ can be used for the generation of electricity, [26].

## 4.5 Hydropower plants of Soča River - Soške elektrarne Nova Gorica

### 4.5.1 HPP Doblar 1 in 2

Doblar 1 was designed during the Austro-Hungarian Empire. After World War I, research continued with an Italian company. In 1939, it started to operate. In 1979, the equipment had become obsolete and inadequate. Three vertical Francis turbines were substituted with equipment from a local manufacturer.

Dolbar 2 was constructed alongside Doblar 1 and uses the infrastructure and equipment of Doblar 1. It started to operate in 2002 with installed power of 20 MW, [27], [28].

### 4.5.2 HPP Plave 1 in 2

Plave 1 was planned parallel to HE Doblar and started to operate in 1940. It has a power of 15 MW. Two vertical Kaplan turbines are installed. It operates reliably and no modernization of equipment is currently needed.

Doblar 1 and Plave 1 satisfy 40% of the demands for electricity in Slovenia.

The design of Plave 2 HPP was based on research results of the available hydroelectric resources. Plave 2 essentially uses the infrastructure of Plave 1. The technology for the construction of the conducting channels was used in Slovenia for the first time. The installed power is 20 MW, and it started to operate in 2002, [29], [30].

### 4.5.3 HPP Solkan

HPP Solkan started to operate in 1984. Three vertical Kaplan turbines with producing 32 MW were installed. The plant is automatic and managed from the control centre of power plants on Soča in Nova Gorica, [31].

### 4.5.4 PHPP Avče

The concept of a pumped-storage hydropower plant is based on increased peak demand of electricity. In times of lower price of electricity (i.e. at night), the water is pumped into the upper reservoir. At times of demand the water flows through turbines to produce electricity. PHPP Avče helps alleviate deficits in electricity production in times of peak demand. The installed power is 180 MW with a vertical Francis one-stage reversible turbine. The maximum drop is 521 m. The pumps needed for pumping storage water have a power 185 MW, [32].

# 5 THE FUTURE OF HYDRO ENERGY IN SLOVENIA

Almost one third of electricity in Slovenia is produced by hydro power, according to Bojnec and Papler, [12]. Experts' opinion is that Slovenia could be able to exploit even more of the available hydropower. Operating possibilities could be doubled, [34].

***Table 1:*** *Production of electricity in large hydro power plants in Slovenia from 2002 to 2010, [12]*

| | Production of electricity from large hydro power plants (TWh) | Production of electricity from all power plants in Slovenia (TWh) | Share of HPP in production of electricity in Slovenia (%) |
|---|---|---|---|
| 2002 | 3313 | 13319 | 24.87 |
| 2003 | 2957 | 12491 | 22.67 |
| 2004 | 4095 | 13835 | 29.60 |
| 2005 | 3461 | 13667 | 25.32 |
| 2006 | 3591 | 13643 | 26.32 |
| 2007 | 3266 | 13636 | 23.95 |
| 2008 | 4018 | 15032 | 26.73 |
| 2009 | 4713 | 15208 | 30.99 |
| 2010 | 4696 | 15260 | 30.77 |

Planned investments for large hydro power plants in the lower course of the Sava River are currently being realised, and there are also investments planned for medium-sized and small hydropower plants. The modernization of existing hydro power plants also aids in increasing the amount of produced electricity. Construction of new small hydropower plants is planned on the Soča and Idrijca Rivers. On the Drava River, the modernization of existing hydro power plants is taking place to ensure the operating conditions for the next 60 years, [34].

Construction of large hydro power plants is multidisciplinary subject, requiring radical changes in the local environment. The opinions of technicians, environmentalists, cultural heritage, sport and tourism specialists are important. Moreover, civil initiative needs to be respected, which can lead to transnational issues. A typical example is the Mura River. There are many hydro power plants installed on river in Austria, Croatia, Hungary, but none in Slovenia [12]. Preliminary preparations for the first hydro power plants on the Mura River in Slovenia are taking place. The construction is planned to be completed in 2020; flow-of-the-river hydro power plants are planned, which have less influence to the surroundings and can be socially more acceptable, [34].

On the lower course of the Sava River, there are two hydro power plants under construction: Brežice HPP and Mokrice HPP. A survey of the area was made between the years of World War I and World War II. The idea for the hydro power plants is written in an article that was published on the 1st of June, 1925 in Technical Journal. In the article, the Authority of Yugoslavian Engineers and Architects states a report of the possibilities and advantages of water energy from the Sava River between cities Brestanica and Čatež [33].

At the beginning of 2011, a public unveiling of plans for hydro power plant Brežice took place in the city hall of Brežice. Construction should be completed in 2016.

Although Slovenia has a good water management, problems are expected in the future. The European directives for water management requires better chemical, quantity and ecological conditions of water and, minimum flows for ecological reasons. This means that there must be more natural and balanced development and better controlled water consumption. That is a new standard in planning and designing environmental politics, [5].

Worldwide, there are extensive possibilities for the future development of exploiting the water sources, especially in developing countries. However, economical, regional, environmental and social factors can substantially affect development. In recent years, the construction of new hydro power plants has significantly decreased, [34].

## 6 CONCLUSION

The efficiency of energy conversion in hydro power plants is generally between 85% and 95%, which is definitely more than in other types of power plants. Consequently, it can be said that the hydro power plant is the most sophisticated developed system for producing electricity.

A relatively large initial investment and long construction period make hydro power plants only slightly profitable, if taking in account only the short-term period between 10 and 20 years. If we consider a longer period of time, reliability and $CO_2$ emission reduction, the hydropower plant is the most suitable renewable energy source, [35].

Electricity production costs over the operating time of hydro power plant are considerably lower in comparison with other renewable sources. This fact reveals that other technologies are in a lower state of development, [35].

The development of hydro power plants in Slovenia is not final. It represents the only optimal way to a “greener” Slovenia. Although larger hydro power plants are not to be defined as entirely harmless for the environment, they can be defined as mainly harmless for the environment.

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# STABILITY ASSESSMENT IN A POWER SYSTEM CONTROL CENTRE

# OCENE STABILNOSTI V NADZORNEM CENTRU VODENJA ELEKTROENERGETSKEGA SISTEMA

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**Keywords:** power system operation, power system monitoring, power system stability

## Abstract

This paper presents a conceptual picture of new stability control possibilities in power system control centres. A potential future state of power system operations and control, with regard to stability assessment, is described and compared to the present state. New technologies have raised the possibility of developing much faster and more widespread stability control that can enable the safe operation of the grid closer to its limits.

## Povzetek

Članek predstavlja konceptualno sliko novih možnosti nadzora stabilnosti v nadzornem centru elektroenergetskega sistema. Opisana je primerjava med prihodnjim in sedanjim stanjem na področju poslovanja in nadzora, povezano z oceno stabilnosti. Nove tehnologije so odprle hitrejše možnost razvoja in nadzora širokega področja stabilnosti, ki lahko omogoči varno delovanje omrežja v področju skrajnih mej.

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# 1 INTRODUCTION

To maintain interconnected power systems in a stable dynamic state, tight control and protection along with the intelligent and diligent operation of such systems are necessary. The general public often take operating details for granted; a catastrophic failure usually happens before power system stability becomes a topic of discussion. Power system faults mostly occur due to natural phenomena, beyond human control. However, if power systems are expected to recover automatically and to continue delivery power, they have to be well designed. If so, very little inconvenience will be experienced by customers. Achieving this is hardly possible without high costs in terms of manpower and equipment. The result of an open market economy is that power systems are forced to operate much closer to their limits of stability; therefore, the decisions of operating personnel must be based on an accurate, online system information and simulations. The current practice of extensive offline simulation of a comprehensive set of possible system operating conditions is good for training purposes but is less useful in real time power system operation situations. As a side effect of liberalized transmission access, networks have to accommodate MW transfers that can be quite different from those for which their transmission networks were originally planned. This is mainly because of the possibility for parallel flows to occur, which is often the case with energy transactions across multi-area systems. Low bus voltages and significant network loadings can occur. The risk of such deteriorated operating conditions, causing blackouts due to instability, increases when a large amount of MW is transferred across a stability-constrained transmission corridor. Furthermore, there are other causes, such as a major disturbance occurring, or even if an otherwise insignificant topology change (such as a minor line trip) happens in a system already operating near its maximum load ability limit. The abovementioned facts highlight the need to compute stability limits for the current and next-day operations processes, thereby foreseeing whether the transmission loading progresses and it is projected to maintain in secure operating reliability limits.

# 2 STABILITY ASSESSMENT IN THE SCADA/EMS

## 2.1 SCADA/EMS

The main function of the control centre is real time data acquisition from the entire power system so that the operator can monitor its operation. Manual operation of controls, such as changing transformer taps or opening or closing circuit breakers is also a significant part of a control centre's function. These functions are all together known as Supervisory Control and Data Acquisition (SCADA), and the control centre is often referred to as SCADA.

Most of the SCADA functions are executed in real time. The monitoring of data generated by a real-time process is a typical example of real-time activity. However, the information generated in SCADA system can also be used in other ways that do not qualify as real time. A data warehouse can be created from historical data and used for post-analysis.

Together with advances in information technology, the computational power of the control centres has grown, and consequently more functions have been added. The most prominent one recently added has been the state estimator. It calculates the real time steady state model of the network. This model can thus be used for two kinds of real time calculations. One, known as security analysis, can study the effects of disturbances (contingencies) and can alert the operator if the post-contingency conditions violate limits. The other, usually using a set of analysis tools known as optimal power flow, can be used to suggest better operational conditions to dispatchers. The abovementioned advanced analytical tools provide better operational guidance to the operator and can provide more efficient operation than the old SCADA systems could. Those functions are now known as Energy Management Systems (EMS).

## 2.2 Real-Time Stability Assessment Possibilities

There are at least three ways to distinguish on-line security assessment, [2]:

- Distinguishing computer analysis and simulation of contingencies from direct monitoring of the current operating point,
- Distinguishing the criteria of types of phenomena: thermal overload, voltage stability problems, or angle stability problems,
- Differing between preventive countermeasures because of a potential disturbance threat and corrective countermeasures that follow the occurrence of the actual disturbance.

The transient stability problem is, unfortunately, far too demanding on computers for true real-time performance, especially if using the conventional time-step simulation method. The outcome of transient stability calculations depends on the initial state, but there is also an issue of the critical dependency on the duration and the location of the fault in the network. Accordingly, determination of system stability requires immense computational effort even for medium-sized networks. Another issue arises regarding the representation of injections in tie lines by SCADA/EMS models. On the border line, the internal network model, and the external system, the incoming power flows (imported power) are usually shown as generated powers being injected into the internal network. Since the abovementioned generators are not actually generators, some other way must found to represent them in the stability calculations. One way of solving this issue is to introduce dynamic equivalents to the model.

The capability of a power system to retain its stability in the presence of slow deviations in the total demand is another type of stability. Practically, an operator needs to know how much additional load can be handled by the transmission system starting from the current state if the load and, consequently, generation and imports would be increased progressively. This can be referred to as steady state stability. Large disturbances caused by faults, loss of equipment, and so on are not part of the transient stability problem. The limit of steady state stability corresponds to the maximum load; moreover, a wheeled power system is able to cope in the current system configuration without collapsing. Imbalances in increases of transmission capacity and growth in the use of electrical power bring many power systems close to limit of stability. Large transfer capacities make power systems more flexible and robust than those lacking the ability to accommodate certain power transfers. One indicator of power system security is certainly the system's transfer capacity.

Real-time cognition and the monitoring of the steady state (voltage) stability limit is highly valuable for the system operator. For that information to be usable as a simple indicator, a limit should be set in terms of a "distance" to instability; specifically, the indicator answers the question about how far the current system is from the defined limit. Voltage control is always a local control, but one must be aware that controlling the voltage at one node affects the neighbouring nodes.

## 2.3 Voltage Stability

Voltage stability is considered to be the ability of a power system to maintain voltages in acceptable ranges at all buses in an observed power system under normal conditions and after disturbances occur. Voltage stability assessment is becoming increasingly complicated as power systems are strengthened. To substantiate that, it should be noted that voltages do not indicate the proximity to voltage collapse point in heavy loading conditions or even in heavily compensated systems. In previous decades, transient angle stability has very rarely been a reason for the restriction of power transfers due to stronger power systems and the development of new equipment technology. Nevertheless, over the past 20 years, the power system blackouts occurring throughout the world have been voltage collapses in most cases.

Voltage instability progress is rather slow, so the dynamic security analysis techniques do not yield satisfying results in voltage collapse detection. Accordingly, separate software is required for voltage security analysis. The continuation of power flow programs use a special technique to obtain a convergence of the power flow solution near voltage collapse conditions and, therefore, are the main off-line tool used to study voltage conditions in networks. This ensures a method for determining the limits in order to avoid voltage collapse. Using these kinds of techniques online has been described in other articles [15], [16]. It has been stated that the static and dynamic security assessment tools provide much information about voltage trends in real time system under contingencies, and that they should be used as a basis for voltage collapse prediction. The static security assessments, for instance, calculate voltages for each contingency, and a voltage collapse limit alert is triggered if there are voltages that are particularly low. If there is no convergence in power flow studies for a contingency, it may be an indication of voltage collapse and continuation of the power flow should be performed.

One problem that exists on online security monitoring is finding the distance of an operating point from stability. Such a measure may be qualitative or quantitative. A qualitative measure does not give the exact megawatt margin but a number, i.e. a stability index that can be interpreted as a degree of stability. For quantitative evaluation, the exact active power value of deviation to stability with respect to a credible scenario is known. Displaying the exact active power value can be computationally highly intense, so the focus is generally in generating a precise voltage stability index. In online applications, these indices are tended to be kept in a way that simplifies their calculation from the online measurements available. If on-line analysis is not possible, the offline study results must be translated into operating limits and indices that are easy to monitor and understand by the operating personnel. The basis of the online security assessment is usually offline computed security limits, such as transfer limits at interconnections. The data warehouse holds the security limits, and the data monitored online is compared for the closest match in the database. Operators commonly recognize these security limits as a security boundary.

The uncertainty of offline security assessments that are typically done months in advance of actual operation is minimized with the use of emerging technologies of online security assessment. The security assessment involves the simulation of the potential contingencies and effects on power systems online, i.e. closest to real time as possible. The study mode of security assessment is useful for determining power transfer capabilities, but the user has to be aware of some conservative assumptions made by the offline system.

If new conditions occur that are potentially not well understood, real-time assessment can immediately assure ongoing operation in a secure state. The first step in comprehensive security assessment is voltage security assessment. It can be done via power flow simulation; since voltage security encompasses localized problems, it is simpler than inter-area dynamic security assessment. Currently, voltage criteria very frequently limit power transfer in power companies. On-line security assessment requires static state estimation, which is difficult to perform in large power systems.

The monitoring of reactive power is an essential part of voltage stability assessment actions. If reactive power sources are near their limits, then voltages are insecure even if voltage magnitudes are within acceptable ranges. Reactive power reserves and high and low reactive power outputs are sensitive indicators of non-secure voltage situations.

Emergency control of voltage stability has the primary goal of halting the progress of an unstable scenario before it progresses toward a voltage collapse. Therefore, timing is critical, i.e. time to detect the instability and time to start applying the emergency control is crucial.

There are a diversity of measures for voltage stability control in emergency conditions, including reactive device switching, tap changer control, generation rescheduling, and load shedding.

# 3 MODERN CONTROL CENTER

The common current technology of monitoring and control may be summarized thusly, [8]:

a. Contingency screening is the basis of the security assessment, which is mainly a steady state power flow analysis.

b. Local information is mostly the basis of the protection and control system. In recent papers, [11], Special Protection Schemes have been described in the global impact sense. Offline studies are used to adjust control strategies, so generally the coordination of different protection and control systems is limited.

c. State estimation output is the basis of the monitoring system. It is subject to a considerable delay at the scale of tens of seconds to minutes. Usually, it is based on the local control area information. Interaction with neighbouring system is limited in most cases.

In order to eliminate these limitations, control centres built in the future are expected to make the most of wide-area information for online, measurement-based real-time security assessment, which would ensure the implementation of an automatic and decentralized control strategy.

Monitoring systems in control centres currently depend on a state estimator that is based on data collected via remote terminal units and SCADA. Future control centres should obtain the system level information from the state measurement module based preferably on a Phasor Measurement Unit (PMU). From the state measurement based on a PMU, higher efficiency is expected than at present since synchronized phasor signals give the state variables, specifically voltage angles. Data collected from Remote Terminal Units (RTU) is not synchronized, and a major effort must be made in order for bad data to be detected and the topology to be checked; therefore, the present state estimation requires more running time and is less robust. In the future, state measurements should replace state estimates.

An innovative technology called “on-line pre-decision” is the future of stability control in power systems. Decision making will be provided in five minutes as a result of online decision-making technology. Using this system will enable the calculation of the decision table to be formed online, and necessary suggestions can also be given to the grid dispatching operators together with instructions.

## 3.1 True Stability Margin Monitoring

If there is possibility of using state variables from state measurement, displaying the true system stability measures in real time is more feasible. Usually, only voltage magnitude is displayed, and that is insufficient information for the determination of the voltage stability margin. “As the system is more stressed and voltage collapse is a recurring threat, the voltage magnitude is no longer a good indicator of voltage stability. Hence, a true indicator of voltage stability margin is needed for better monitoring”, [7]. Most of the current technology relies on monitoring frequencies on a small area. The frequency and phase of all power generation units must keep their synchronism within narrow limits in order to keep the power grid stable. If the generator frequency falls below 50 Hz, it will rapidly heat in its bearings and eventually destroy them. Therefore, at that point, frequency protection detects frequency variations and sends a command to the circuit breakers and trips a generator out of the system. Even small frequency changes can be indicators of instability in the grid. In order to enable identifying the fault in remote locations, and to prepare for possible instability, the frequency in the wider area and its change must be monitored and traced. Using the proposed technology together with the assistance of the wide-area GIS data would make displaying the voltage stability margin and trends of changes in frequency in real time on the top layer of the actual wide-area GIS map possible. Current technology mostly relies on simulations and visualizations of local measurements. In the future, a measurement-based stability margin monitoring system will greatly aid operators in the prediction and identification of potential real-time operation problems.

## 3.2 Dynamic Security Assessment

After outages, a static security assessment checks for limit violations, but with assumes that the power system is in a steady state in the post-outage time. Since outages are usually the results of an accidental short-circuit that causes the isolation of the short-circuited elements by protective systems, the power system may experience significant outing in the voltages and power flows during such disturbances, [10]. If a severe enough disturbance occurs, these swings may cause generators to become unstable. In that case, widespread outages would occur instead of a single outage. Those short circuits or contingencies that cause instabilities are identified by the dynamic security assessment. No contingencies should make the system unstable if it is operated within its limits and properly planned. Nevertheless, in real-time operation, the power system happens to end up in conditions that were not foreseen when the planning was done. It is important to analyse whether such contingencies can make the system unstable. The stability calculations are even more computationally intensive and time consuming than the power flow calculations, so the online checking of stability in hundreds of possible contingencies is an exhausting task. Dynamic security assessment has become a reality thanks to the continuous falling of the price-performance ratio in information technology. Running a static security assessment has led to some new techniques as well as new algorithms, all of which have been very useful in developing dynamic security assessment tools. Contingency screening based on the concept of rapidly isolating the worst contingencies is also applicable for dynamic security. The task is to isolate the few unstable contingencies among most of the stable ones. A rapid approximate method is needed via contingency screening in order to determine the stability of the system. One common and accurate method is the time domain solution performed over sufficiently long time periods that allow the trajectories to depict stable or unstable behaviour. The approximate method calculates the time domain solution for a short time just beyond fault clearing and then projects the stable or unstable behaviour from these trajectories by performing other calculations. There are various techniques that are used: transient energy and their margins, signal energy, different coherency measures and the equal area criterion, [10]. Ranking the contingencies in order to determine the worst cases is possible via these measures. The traditional time domain solution can be used to accurately determine the stability of the system once the worst cases are determined. The abovementioned techniques work quite well for systems that are at high risk for instabilities caused by a lack of synchronizing power. These instabilities can be detected using fewer calculations because they occur very quickly, within a second or so. Those instabilities that occur after several oscillations because of negative damping are difficult to detect without detailed and longer simulation or by using modal analysis. Online dynamic security assessment is still not available for these kinds of systems, and conservative operating limits calculated offline are, unfortunately, the only answer. When the dynamic security assessment detects instabilities (although those are rare cases), the operator, once alerted, needs to take preventive action. When a contingency occurs, the rush of instability is very fast, so the possibility of the operator to take manual corrective action is rather slim. Sometimes, the operator may be able to trip special protection devices to shed load or generation, which will ensure stability. A common case is the modification of the generating pattern, which the operator uses as the available preventive action. Because this increases the cost of operation, methods to quickly calculate the minimum changes required to maintain stability for a particular contingency are being explored. The simplest way known to do this is by recalculating the power flow limits on a certain transmission corridor.

## 4 WIDE-AREA STABILITY AND VOLTAGE CONTROL

There is a synergy between on-line security assessment and wide-area controls. Wide-area stability controls are presently utilized mainly as so-called special protection systems. They can be also referred as remedial action schemes. These schemes are about the direct detection of severe outages. Detection is followed by transferring commands for generator tripping or other discrete feed-forward stabilizing actions. Using such controls is commonly based on direct monitoring, i.e. system conditions observed by control centre operators and/or dispatchers; the system conditions for arming such tripping are determined by off-line simulation and analysis. These controls only operate for predetermined outages, in comparison to response-based controls. It is realistic to expect more sophisticated wide-area stability controls in the future. While local stability controls are normally used and generally preferred, there are opportunities for using more advanced wide-area or centralized controls. Superior observability is the driving force behind using remote signals, [2]. Centralized controls can take action based on a large information base, and they are often a switching action.

### 4.1 Wide-Area Protection System for Stability

The modern power system and its stability characteristics are becoming increasingly complicated along with the increase of transmission distance, growth of loads and the composite structure of HVAC and HVDC systems. There are advanced systems that are made for the purpose of protecting the power system from blackout, and they also can significantly improve the stability of the power grid. The main defence lines of that system are:

a. Fault Clearing. It is based on accurate and fast protective relays whose job is to ensure that the fault can be quickly cleared, thereby ensuring the stability of power system. There are reliable and high-speed protection products that can ensure that the fault is quickly cleared before the system loses the stability, thanks to innovative protection elements that can significantly reduce the pickup time to trip the fault.

b. Load Shedding and generator shut-down is used in severe contingencies for emergency control. Rising of the load and generation unbalance will provoke the wide-area protection to take some intervention, such as generator shut-down or load-shedding, to ensure stability. If a stability loss in the power system is detected after the serious fault is cleared, wide-area protection and the control system calculate the power flows and generate corresponding control strategies. Control commands are then sent to the executing device so that prompt intervention can be made in order to maintain the stability of the system.

c. Out-Of-Step Islanding is local corrective control for extremely severe contingencies. If the above-described fault clearing and load shedding cannot maintain the power system's stability, then the third line of defence will be activated in order to avoid the collapse and minimize the load loss. This third line includes control devices such as out-of-step protection and frequency-voltage to maintain the system stability. The theory behind the out-of-step model of system protection is avoiding any element in power system that may trip while stable swings are on. When synchronicity is lost between two areas of same power system, or two interconnected systems, these areas must be detached as soon as possible. This is performed automatically in order to avoid equipment damage and the shutdown of major portions of the power system, [14]. Uncontrolled circuit breakers trips while the power system is in an out-of-step state can cause equipment damage and potential danger for utility personnel. With this method, it can be concluded that controlled manipulations of indispensable power system elements are necessary in order to prevent equipment damage and severe wide-area power outages, as well as to minimize the negative effects of the disturbance.

### 4.2 The Future

The merging of information and control can definitely be considered to be the future in on-line security assessment and wide-area control. One distinct challenge is the development of wide state estimation on interconnections. Rapidly developing information-age technology is crucial in meeting this challenge. This includes advanced systems such as integrated substation and power plant control and protection, advanced sensors, phasor measurements, communications through fibre optic and WAN and LAN technologies. In control centre-based centralized control, where a large measurement and information database is available, new control technologies such as intelligent automated controls may be applicable.

## 5 CONCLUSION

Adequate planning and proper operational procedures with smart decision making are crucial for maintaining the security of the power system. Current technology and a vision of the future are discussed, and a comparison between those two is given. Modern technology, specifically in terms of improvements in computers, communications and controllers, is already being used in power systems in many ways. By combining these technologies, it is possible to develop wide-area controls for power systems, which enable controlling stability better and, consequently, increasing transmission limits. New control technologies, i.e. intelligent controls, may be applied for control centre-based centralized control where large amounts of measurement and information data base are available. Steady-state contingency analyses are generally the best that the present on-line analyses in control centres typically perform. The reach of those analyses is analysing each credible contingency event by using contingency power flow studies and identifying line flow violations. Future control centres are expected to have online time domain-based analysis. That would imply the ability to perform voltage stabilization and transient angular stability in real time.

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# A SPATIAL EVALUATION OF THE IMPACT OF AIR POLLUTION: A GIS-BASED APPROACH

# VREDNOTENJE PROSTORSKIH VPLIVOV ONESNAŽENJA ZRAKA NA PODLAGI GIS-OV

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**Keywords:** air quality indicators, Bosnia and Herzegovina, living environment, Montenegro, Slovenia, spatial evaluation


## Abstract

The common denominator of the three areas discussed in this paper is basin-type terrain; all areas of the research were thoroughly transformed by human activities (mining, production of energy, industry, settlements and associated infrastructure) in the second half of the 20th century:

1) the wider area of Plevlja Community in Montenegro; air quality indicators were monitored at 19 sampling places;

2) Tuzla basin in Bosnia and Herzegovina as a heavily polluted landscape (industry, energy production, heating of private furnace); 20 monitoring sites were placed there. The anthropogenic environmental pressures have not been reduced;

3) Šalek Valley (Slovenia) as an example with an entire range of well-established technological environmental solutions and measures in the manufacturing sector with 34 measuring points.

In all three cases, very active transport activity caused by different users represents significant environmental pressure.


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The evaluation of the quality of the living environment was made indirectly, using the environmental indicator method. The basis of the survey was carried out during the winter heating period, since we intended to determine the presence of some air pollutants and their effects (especially spatial ones) on the quality of the living environment. Principally, the researched areas are more delicate in the winter period, because private heating system fossil fuels are used. We monitored sulphur dioxide and nitrogen dioxide. In the survey, the method of measurement with diffusion tubes placed at various outdoor locations of the living environment was used, with locations in rural and urban area.

We wanted to add an applied value to the preliminary results of measurements, so these results were used for the spatial presentation below. Both can play an important role in the municipal spatial planning of socio-economic activities, e.g. settlement, educational and medical institutions, manufacturing facilities.

Furthermore, we intend to show the obtained results of the air quality level in relation to the data on morbidity in the treated areas, i.e. cardiorespiratory diseases.

## Povzetek

Območja raziskave so v 2. polovici 20. stoletja močno preoblikovale in obremenile človekove dejavnosti: rudarstvo, energetika, industrija, poselitev in pripadajoča infrastruktura. V prispevku obravnavamo tri območja s še enim skupnim imenovalcem - kotlinski pokrajinski tip:

1) širše območje občine Plevlja v Črni gori, kjer smo antropogene pritiske na kakovost zraka spremljali na 19 merilnih mestih;

2) Tuzlanska kotlina v Bosni in Hercegovini, 20 merilnih mest, okoljsko obremenjevanje ne pojenjuje (kemična industrija, termoenergetika);

3) Šaleška dolina s celim nizom uvedenih dobrih tehnoloških okoljskih rešitev in ukrepov v proizvodnih dejavnostih, kjer smo izpostavili 34 merilnih mest.

Kakovost bivalnega okolja smo vrednotili posredno, z merjenjem kazalcev za zrak v zimskem (kurilnem) obdobju. Tako smo se odločili predvsem zaradi tujih območij, kjer v hladnem delu leta zasebna kurišča zaradi rabe fosilnih goriv močno vplivajo na kakovost zraka. Ugotavljali smo prisotnost nekaterih zračnih onesnažil ter njihovo prostorsko razporeditev in vpliv na kakovost bivalnega okolja. Spremljali smo vsebnost žveplovega dioksida in dušikovega dioksida v zunanjem zraku. Na terenu je bila uporabljena metoda merjenja s pasivnimi difuzivnimi vzorčevalniki, nameščenimi na lokacije s funkcijo bivalnega okolja.

Rezultatom meritev smo želeli dodati aplikativno vrednost in jih prikazali tudi prostorsko. Imajo lahko pomembno vlogo pri nadaljnjem umeščanju posameznih dejavnosti, npr. poselitev, izobraževalne in zdravstvene ustanove, ter proizvodni obrati v preučevanih območjih.

V nadaljevanju raziskave želimo prikazati dobljene rezultate kakovosti zraka v razmerju do podatkov o obolevnosti, predvsem kardiorespiratornih bolezni, na obravnavanih območjih.

# 1 INTRODUCTION

The combination of environmental impact assessments (EIA) and GIS (Geographical Information System) could provide an approach to explore the scope of the evaluation of air quality.

GIS can be used to obtain the spatial information for the assessment of air pollution impact in various suburban and rural areas. Such information serves as an example to quantify the negative impacts of ambient air quality associated with any planned projects of anthropogenic origin. The approach utilized the spatial evaluation of air pollution and aids in providing critical insight to the assessment, which is not apparent while carrying out such activity in the traditional manner. That kind of study could encourage spatial planners to make wider application of the technique for an in-depth assessment of environmental impacts, [3].

The Slovenian Environment Agency has been monitoring air pollutants in the ambient air by using diffusive samplers since 2003, [7].

Slovenia has been obliged to adopt two European Directives on ambient air quality. The directives establish, [10]:

- Ambient air quality standards, in particular the target, limit, warning, critical and alert values for ambient air quality in order to avoid, prevent or reduce adverse effects on human health and the environment,
- Ways of informing the public on overcoming the threshold values for certain pollutants,
- An obligation to draw up plans and measures for maintaining and improving air quality.

Fieldwork was carried out in three areas, in different nations, but related by geophysical characteristics. All belong to the basin area type, especially sensitive in terms of the self-cleaning ability of the air. Locally, the most variable factors depending on the terrain are the wind speed and the wind direction. The direction of wind is usually dominated by the axis of the valley. The wind at the bottom of the valley is the weakest, while its speed increases with the height of the valley slopes, [8].

Winter is also unfavourable due to frequent foggy days and the occurrence of temperature inversions. Two areas of inversion have been identified: a) a terrestrial temperature inversion layer, which protects the bottom of the valley from the air pollution, as there are usually high exhaust chimneys of thermal power plants up to 230 m, and b) a higher subsidence temperature inversion layer, that closes the flue gas path from a thermal power plant. These accumulate below the top layer of the air with a temperature inversion, and then the slope winds move down towards the bottom of the valley; as a result, the terrestrial inversion is not achieved, [6].

The researched sites have inherited similar social development policies. Their appearance today is energy-intensive and industrialized (there are thermal power facilities of national significance), concentrated with settlements and associated infrastructure. Šalek Valley represents an isolated role as an example of a thoroughly improved environmental landscape, while environmental measures in the other two areas are lagging behind (both in the perception of air pollution and the implementation of remediation). Periods of exposure to diffusive samplers coincided with a cold period due to a lack of available sampling materials, and measurements were performed sequentially in Šalek Valley between the 20 November and 4 December 2009, from 27 October to

18 November 2010 in the Tuzla basin, and from 27 October to 22 November 2012 in Montenegro.

We wanted to determine the presence of certain air pollutants and their spatial distribution. To measure the quality of the living environment, we deliberately chose to use the fossil fuels most consumed in winter. Based on the results of air quality measurements and trends of urbanization, we can systematically track changes in the environment and coordinate them with the spatial needs of different socio-economic activities, [4].

## 1.1 Air quality indicators

The Slovene Regulation of sulphur dioxide, nitrogen oxides and particulate matter in ambient air, [12], was replaced in 2011 by the Regulation on ambient air quality, [11]. By 2005, the hourly limit value for nitrogen dioxide was 200 g/m³, which was not supposed to happen more than 18 times per calendar year. Later, the threshold value steadily decreased (in 2005 50 g/m³, in 2006 40 g/m³, in 2007 30 g/m³, in 2008 20 g/m³ and from 2009 onward 10 g/m³).

The value for the calendar year until 2005 amounted to 40 g/m³, then decreased (in 2005 10 g/m³, in 2006 8 g/m³, in 2007 6 g/m³, in 2008, 4 g/m³, and from 2009 onward 2 g/m³).

***Table 1:*** *Allowed concentration, limit values and tolerance (in mg/m³) for NO2 and $SO_2$, comparison between Slovenia, Montenegro and Bosnia and Herzegovina*

<table>
<tr><th rowspan="2"></th><th colspan="2">$SO_2$ [µg/m³]</th><th colspan="2">$NO_2$ [µg/m³]</th></tr>
<tr><th>hourly</th><th>daily</th><th>hourly</th><th>annual</th></tr>
<tr><td>Bosnia and Herzegovina</td><td>350 (alarm value 500)</td><td>125</td><td>200 (alarm value 400)</td><td>40</td></tr>
<tr><td>Montenegro</td><td colspan="2">350</td><td colspan="2">350 or 200 bay mass flow of 1800 g/h</td></tr>
<tr><td>Slovenia</td><td>350 (may not be exceeded more than 24 times per calendar year)</td><td>125 (may not be exceeded more than 3 times per calendar year)</td><td>10</td><td>2</td></tr>
</table>

### 1.1.1 Nitrogen Oxides

The indicator shows the total emissions of nitrogen oxides (NOx), indicating mostly the impact of traffic. In 2011, road transport Slovenia contributed 54% of the total emissions of nitrogen oxides. The energy sector is the second largest source of these pollutants. Data for annual NOx emissions for Slovenia in the period from 1987 to 2007 showed a reduction of emissions in 2007 by almost 20% compared to 1987. The decrease happened due to higher proportion of vehicles with catalytic converters. NOx emissions in 2007 were 1% lower than the predicted target value. The level of air pollution with nitrogen dioxide in the 1992–2008 period fell below the prescribed limit average annual concentration. Only in Maribor did the annual concentration throughout the 1992–2008 period exceed the critical value of annual NOx for the protection of vegetation and ecosystems, mainly due to the influence of surrounding traffic.

### 1.1.2 Sulphur dioxide

In Slovenia, the level of ambient air pollution with sulphur dioxide in urban areas, according to the limits laid down in the Regulation on ambient air quality, [11], does not reach levels dangerous to human health. Moreover, critical annual concentrations for the protection of vegetation are not exceeded. Improvement of the air quality in the previous decade is attributable to the higher grade of the fuel (higher quality coal, oil, gas) plus activation of desulphurization plant of the TPP Šoštanj and Trbovlje. In the Zasavje region, a purifying plant in the Lafarge factory was installed. In Slovenia, the $SO_2$ emissions were reduced by 2007 to 94% compared to 1980. The decrease was primarily due to lower and controlled releases from power plants and the use of higher quality fuels. Emissions of $SO_2$ in 2007 were 47% lower in comparison to the predicted target value.

# 2 METHODS AND MATERIALS

## 2.1 Diffusive samplers method

As a basic material for the research fieldwork, we used the diffusive samplers. This method works on the principle of pollutant transport in the sampler by means of molecular diffusion. Samplers are tubes that stay open at one end during the time of sampling and are continuously exposed to the ambient air. At the closed end of the tube, there is a membrane with a reagent to a given substance (pollutant). Pipes should be opened just before exposure and closed immediately afterwards. The recommended exposure time is 14 to 21 days. The advantages of this method are flexibility, convenience, affordability and, therefore, the possibility of a recurrence of sampling, which increases the usefulness of the method. Due to the lower reliability of the method, it can be complemented by parallel measurements of data at automatic stations. The results provide with information about the average pollution values for the period of exposure, but not maximum, hourly and daily values, as required by legislation, [11].

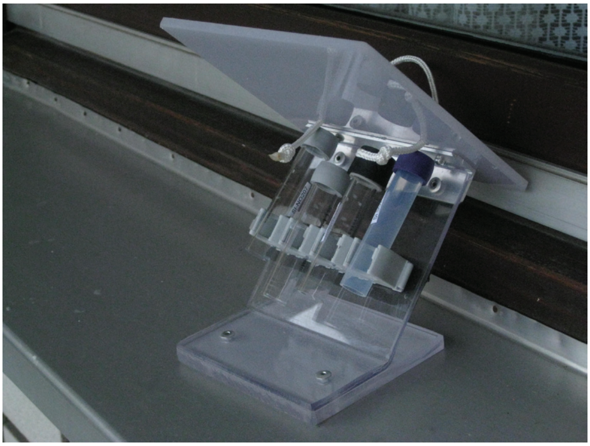


***Figure 1:*** *Exposure of diffusive samplers*

## 2.2 Inverse Distance Weighted method (IDW)

Each method of interpolation determines or estimates the value of the measurements at selected locations, which lie in locations with a known monitored value. The quality of the approximated model surface depends on the measurement that is interpolated, the allocation (distribution) of sample points, and the chosen interpolation method. In principle, the denser and more homogeneous distribution of the given points leads to a credible result.

The method of inverse distance weights (IDW) assumes that any given sample point has its local impact, which decreases with the inverse potency of the distance from the interpolated point. Points closer to the interpolated point are weighted (influential) more than more distant ones. The IDW method assesses the value of the intersection of the two profiles of the cellular network by calculating the average value of the given sample points near each intersection. This approach thus allows a greater impact of closer points than more distant ones. The method is applicable in cases in which the influence of the studied variables decreases with the distance from the sample locations. For example, the interpolation of point location of pollutants, the concentration decreases with distance from the location of contaminants, and the use of this method is logical. The disadvantage of this method is that the approximated surface can reach local extremes (minima and maxima) only in the given point, which does not reflect the situation in nature. The IDW method is suitable for the preview of the approximated surface, [2].

# 3 RESULTS AND DISCUSSION

The data for measured values of the monitored air quality indicators were processed with the basic statistics. Due to the low number of sample points (19–34), the most appropriate interpretation of the results was to use the mean value of the median.

Measurements revealed the highest mean (median) in the measured period for $NO_2$ emissions in the municipality Plevlja in Montenegro (20.22 mg $NO_2/m^3$). The Tuzla basin followed with 13.68 mg

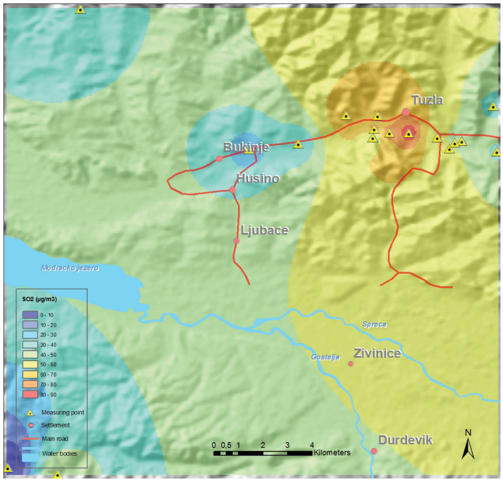
$NO_2/m^3$, and the least burdened air with $NO_2$ was measured in Šalek Valley.

The indicator of sulphur dioxide in the ambient air pollution had the highest value of 45.85 mg $SO_2/m^3$ in the area of Tuzla. The wider area of the municipality of Plevlja in Montenegro tended to have almost the half of the concentration of sulphur dioxide pollution (23.57 mg $SO_2/m^3$), while the average value of this indicator in Šalek Valley was negligible (0.01 mg $SO_2/m^3$).

***Table 2:*** *The calculated mean value (median), average, standard deviation from the average and maximum measured concentrations of $NO_2$ and $SO_2$ in the discussed period and in selected areas.*

| Area/Pollutant | $NO_2$ [µg/m³] | $SO_2$ [µg/m³] |
|---|---|---|
| **TUZLA (n=20)** | | |
| median | 13.68 | 45.85 |
| average | 14.02 | 44.95 |
| st. deviation | 11.56 | 23.22 |
| maximum | 37.99 | 88.49 |
| **PLEVLJA (n=19)** | | |
| median | 20.22 | 23.57 |
| average | 19.61 | 23.95 |
| st. deviation | 8.69 | 12.47 |
| maximum | 34.08 | 50.14 |
| **ŠALEK VALLEY (n=34)** | | |
| median | 13.29 | 0.01 |
| average | 14.96 | 1.61 |
| st. deviation | 3.99 | 2.65 |
| maximum | 22.21 | 9.42 |

The maximum concentration of $NO_2$ was measured in Tuzla (37.99 mg $NO_2$/m3). The data for Plevlja showed 34.08 mg $NO_2/m^3$ and the least air pollution pressure was evident in Šalek Valley (22.21 mg $NO_2/m^3$). Even after the measured concentrations of $SO_2$, as calculated by the maximum value, the outstanding result was found in the Tuzla basin (88.49 mg $SO_2/m^3$), followed by the municipality of Plevlja (50.14 mg $SO_2/m^3$). The least laden ambient air with sulphur dioxide was measured in Šalek Valley (9.42 mg $SO_2/m^3$).

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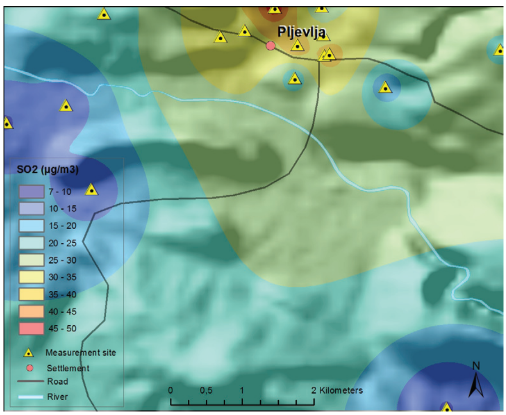


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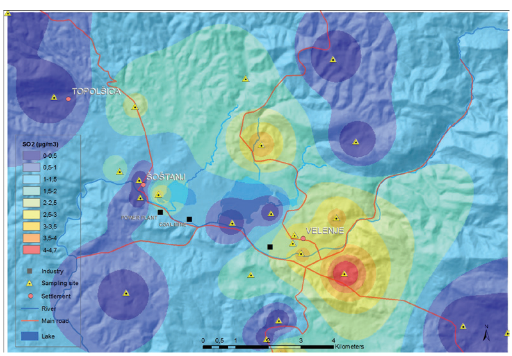



(c)

***Figure 2:** The spatial display of the measured values for $SO_2$ in the researched areas (a) - Tuzla basin in Bosnia and Herzegovina (b) - the area of the Plevlja municipality in Montenegro and (c) - Šalek Valley in Slovenia*

The spatial distribution of the measured indicators for the quality of air produced by the GIS (Geographic Information System) approach reflects the pollution of the individual parts of the areas of research. Based on the pollution measurement of the ambient air and the appropriate number of repeated measurements with the denser (systematic) monitoring network, we could determine more detailed findings on air quality. In addition, microclimatic conditions (flow of air) and meteorological data for days of exposure of the samplers should be taken into account.

Such data on air pollutants may be an appropriate form of assistance for spatial planners in assessing and allocating activities and their potential effects on the environment. The data are also useful in the design of remedial measures and programmes.

## 3.1 Tuzla basin

Measurements were performed at altitudes of 221 to 326 m above sea level. They revealed a very strong contamination of the site Tuzla basin with sulphur dioxide. The highest measured values are shown in a cartographic representation for the area Mejdan in the city centre, close to the university and associated faculties, [14]. The highest measured value (88.49 mg $SO_2/m^3$) was also there. The lowest values were found at monitoring sites Bukinje, west of the city.

Data for $NO_2$ showed the lowest values in urban areas of Mejdan and Stupine, a residential (blocks of apartments) quarter, which is located south east of the city centre. Low values (up to 15 mg $NO_2/m^3$) were also measured south from the eastern artery into the city. Maximum values reflect the results of measurements of $NO_2$ in the northeast outskirts of Tuzla basin (Grabovica Donja).

## 3.2 Plevlja

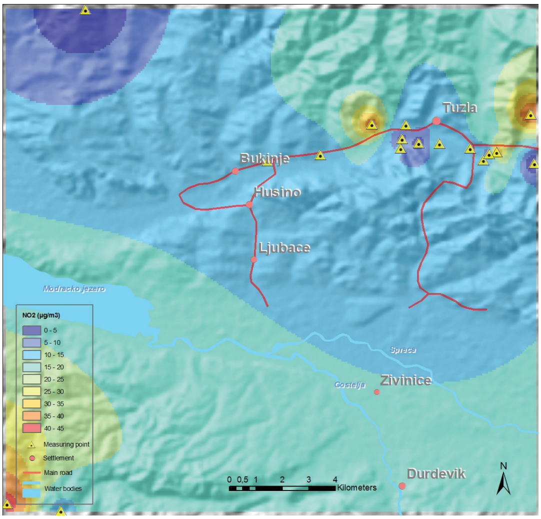
The measuring points were set at altitudes of 753 to 1017 m. The basin type of landscape has a typical spatial distribution of sulphur dioxide, i.e. heavily laden at the bottom of the depression and pollution-free edge of the basin. The highest values were measured at three urban locations (between 40 and 50 mg $SO_2/m^3$), the maximum at the measurement site Moćevac (50.14 mg $SO_2/m^3$) in the northern part of the measurement area. Values from 30 to 40 mg $SO_2/m^3$ were characteristic for the rest dense populated area of Plevlja. Less pollution (7-15 mg $SO_2/m^3$) was observed by the stations at the W and SE of the basin perimeter.

According to the results of $NO_2$ measurements, three locations in the N and NW part of the studied area were outstanding. Again, as the most polluted areas there were three urban sites with the highest value of $NO_2$ at the location Moćevac $NO_2$ (34.08 mg $NO_2/m^3$). The lowest values were measured in the western part of the area, outside the dense populated town Plevlja.

### 3.3 Šalek Valley

Diffusive samplers were exposed between 352 and 772 m above the sea level. Despite the very low concentrations of burdening ambient air in the valley with $SO_2$, peak values occurred on the SE edge of the Velenje basin (category 4 to 4.7 mg $SO_2/m^3$). Values were reduced to the NW in the town of Velenje with the wider hinterland, where we measured values between 2 and 3.5 mg $SO_2/m^3$. The lowest values were evidenced at all other measuring points of the basin periphery (0 to 0.5 mg $SO_2/m^3$).

Maximum values for NO2 were measured at the very southern edge of the basin. The sites of the researched area mostly expressed very low levels, with the exception of a mountain location: Graška Gora (category 20 to 25 mg $NO_2/m^3$).

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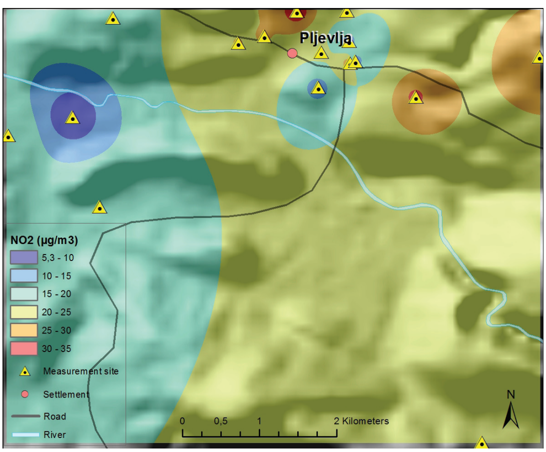


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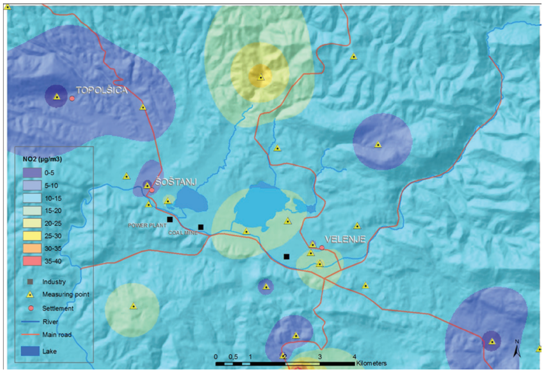


(c)

***Figure 3:*** *The spatial display of the measured values for $NO_2$ in the researched areas (a) Tuzla basin in Bosnia and Herzegovina, (b) the area of Plevlja municipality in Montenegro and (c) Šalek Valley in Slovenia.*

## 3.4 Air Quality Index (AQI)

The AQI (of the Environmental Protection Agency (EPA)) is an index for reporting daily air quality. It explains how clean or polluted the monitored air is and what associated health effects might be of concern. The higher the AQI value, the greater the level of air pollution and the greater the health concern. For example, an AQI value of 50 represents good air quality with little potential to affect public health, while an AQI value over 300 represents hazardous air quality. The purpose of the AQI is to aid in understanding what local air quality means to peoples' health.

Each category corresponds to a different level of health concern. The six levels of health concern and what they mean are, [5]:

***Table 3:*** *AQI categories and Health Concern*

| Air Quality Index Levels of Health Concern | Numerical Value | Meaning |
|---|---|---|
| **Good** | 0 to 50 | Air quality is considered satisfactory, and air pollution poses little or no risk |
| **Moderate** | 51 to 100 | Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution. |
| **Unhealthy for Sensitive Groups** | 101 to 150 | Members of sensitive groups may experience health effects. The general public is not likely to be affected. |
| **Unhealthy** | 151 to 200 | Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects. |
| **Very Unhealthy** | 201 to 300 | Health warnings of emergency conditions. The entire population is more likely to be affected. |
| **Hazardous** | 301 to 500 | Health alert: everyone may experience more serious health effects |

The highest AQI $SO_2$ concentration results were in the Tuzla area. The third category (AQI index: 146) evidenced an increased vulnerability for the people with respiratory illnesses. There are also warnings relevant to inhabitants subject to asthma in other two researched areas, but with no health effects and cautionary statements. The air quality state in the Bosnian fieldwork area required urgent sanitation measures.

***Table 4:*** *Air Quality Index (AQI) in the discussed areas after calculation of $SO_2$ concentration*

| Area | AQI | AQI Category | Sensitive Groups | Health Effects Statements | Cautionary Statements |
|---|---|---|---|---|---|
| **Tuzla** | 146 | Unhealthy for Sensitive Groups | People with asthma are the group most at risk. | Increasing likelihood of respiratory symptoms, such as chest tightness and breathing discomfort, in people with asthma. | People with asthma should consider limiting outdoor exertion. |
| **Plevlja** | 9 | Good | People with asthma are the group most at risk. | None | none |
| **Šalek Valley** | 6 | Good | People with asthma are the group most at risk. | None | none |

(AQI calculation accessed at http://airnow.gov/index.cfm?action=resources.conc_aqi_calc)

Measurements of $NO_2$ concentrations revealed the Plevlja area to be the most polluted with nitrogen oxides. An AQI of 102 indicated unhealthy environment for people with increased likelihood of respiratory diseases, breathing discomfort and lung disease. Šalek Valley and the Tuzla basin area also seemed to be risky living environments for children and elderly with respiratory illnesses. Due to the moderate AQI category, prolonged and heavy outdoor exposure should be avoided.

***Table 5:** Air Quality Index (AQI) in the discussed areas after calculation of $NO_2$ concentration*

| Area | AQI | AQI Category | Sensitive Groups | Health Effects Statements | Cautionary Statements |
|---|---|---|---|---|---|
| **Tuzla** | 71 | Moderate | People with asthma or other respiratory diseases, the elderly, and children are the groups most at risk. | Unusually sensitive individuals may experience respiratory symptoms. | Unusually sensitive people should consider reducing prolonged or heavy outdoor exertion. |
| **Plevlja** | 102 | Unhealthy for Sensitive Groups | People with asthma or other respiratory diseases, the elderly, and children are the groups most at risk. | Increasing likelihood of respiratory symptoms and breathing discomfort in active children, the elderly, and people with lung disease, such as asthma. | Active children, the elderly, and people with lung disease, such as asthma, should reduce prolonged or heavy outdoor exertion. |
| **Šalek Valley** | 69 | Moderate | People with asthma or other respiratory diseases, the elderly, and children are the groups most at risk. | Unusually sensitive individuals may experience respiratory symptoms. | Unusually sensitive people should consider reducing prolonged or heavy outdoor exertion. |

(AQI calculation accessed at http://airnow.gov/index.cfm?action=resources.conc_aqi_calc)

# 4 CONCLUSIONS

Monitoring of ambient air quality is a key activity in evaluating the state of the living environment or assessing and planning additional burdens in a selected area. Data on air pollution in Slovenian cities suggest high levels of pollution with $NO_2$. In addition, Slovenian urban areas have been increasingly more polluted with particulates of <PM10 microns. In 2010, the European Commission initiated proceedings against Slovenia at the European Court of Justice for failure to comply with environmental legislation.

Measurements and calculated data indicate the Tuzla basin to be the most polluted area. Considering the basic statistical parameters, the indicators of $SO_2$ and $NO_2$ were recorded as the highest (88.49 mg $SO_2/m^3$ and 37.99 mg $NO_2/m^3$), as well as mean values for the indicator $SO_2$

(45.85 mg $SO_2$/m3). The highest calculation of the mean values of $NO_2$ was measured in the wider area of the municipality Plevlja in Montenegro (20.11 µg $NO_2/m^3$) and is almost identical to the maximum measured value for the Šalek Valley (22.21 µg $NO_2/m^3$). At the same time, there are less stringent legal requirements for the limit thresholds of the indicator considered, which means that they have not been moving towards more radical action in relation to the quality of air.

Therefore, the results for the Šalek Valley are a wide disparity in the positive sense. The mean values for $SO_2$ concentrations are low (0.01 mg $SO_2/m^3$), while the maximum measured value of the same indicator was 9-42 mg $SO_2/m^3$. The results for nitrogen oxides are the most favourable for the Šalek Valley compared to the other two areas. Taking into account the legal provisions for the air quality, the results dictate a need for further reducing of $NO_2$ emissions.

The method of diffusive samplers is suitable for ambient air quality monitoring. For a relatively low cost, it offers results on the spatial distribution of air pollutants, and the resulting data are a welcome help to land-use planners in the assessment and planning of new activities in the area. The relevance of method could be supported by the denser network of monitoring sites, repeated measurements and simultaneous use of other planning methods. An appropriate amendment would provide the data on the local terrestrial air circulation.

The acquired results are just one of the models that examined the links between urbanization and the quality of environmental resources and they proposed continuation of the work. Environmental pressures have not been reduced, nor have energy needs. The trend of space burdening has been intensified by dense settlements.

Environmental capacity of the area, not just urban, should be considered broadly because of its scarcity and mainly due to overburdening. There are many factors that affect the quality of the environment. Moreover, studies similar to this one should consider more of them (weather, microclimate characteristics, demographic data, etc.) to enable more definitive conclusions about the air quality in the mentioned areas with the help of the results obtained. In general, we designed a framework for the systematic assessment monitoring of changes in air quality.

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# THE OPTIMIZATION OPTIONS OF WATER SUPPLY SYSTEMS IN TERMS OF ENERGY CONSUMPTION

# MOŽNOSTI OPTIMIZACIJE VODOVODNIH SISTEMOV Z VIDIKA PORABE ENERGIJE

Ivan Žagar[ℜ]

**Keywords:** heterogeneous water supply system, parameters of optimizations, energy consumption, economic indicators

## Abstract

The provision of drinking water is a basic communal utility. Unfortunately, economic aspects cannot be ignored while ensuring the quality of healthy drinking water. Both the quality and the economics of the supply are influenced by numerous parameters that are determined by natural resources, technological processes, as well as by potential energy use within the water supply system. The optimization options of water supply systems in terms of energy consumption as well as in terms of other parameters are shown in the practical case of a heterogeneous water supply system in the municipality of Slovenska Bistrica.

## Povzetek

Zagotavljanje pitne vode je ena od osnovnih komunalnih dejavnosti, pri čemer pri zagotavljanju kvalitetne zdrave pitne vode ne gre zanemariti tudi ekonomskih učinkov. Tako na kvaliteto kot na ekonomijo oskrbe vplivajo številni parametri, ki jih pogojujejo tako naravne danosti, tehnološki procesi, kot tudi potencialna energetska izraba znotraj vodovodnega sistema. Možnosti optimizacije vodovodnih sistemov glede na porabo energije kot tudi druge parametre so prikazane na praktičnem primeru heterogenega vodovodnega sistema oskrbe na območju občine Slovenska Bistrica.

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# 1 INTRODUCTION

Different types of water systems for the supply of drinking water exist due to geographical, climatic and other conditions. A quality water supply requires adequate quantities of drinking water. Even if consumption is reduced to the greatest extent practically possible, economic indicators cannot be ignored, even more so when they are dependent on legal requirements and the parameters dictated by the environment. Particular attention is given to energy consumption. The type, quality and quantity of water resources in a heterogeneous water supply system (the combination of natural sources, surface water supplies from the aquifers as well as the pumping stations from the wells) cover a number of parameters that dictate the necessary technology for the preparation of drinking water and of the entire supply system.

The heterogeneous water supply system under consideration in this paper is supplied from multiple water resources that are dependent on foreign energy as energy consumers. The water supply system is expanded with multiple water resources. Consequently, the economic use of energy and water is of crucial importance in their management. The main supply system connects eight water resources with very different characteristics, capacities and vulnerabilities.

# 2 THE STARTING POSITION OF WATER SUPPLY SYSTEM

## 2.1 General information about water resources, description and characteristics

Figure 1 shows the positional arrangement of water resources, water storage tanks and their capacities. It also shows the water supply network, which is intended for supplying the population with drinking water and the provision of fire safety.

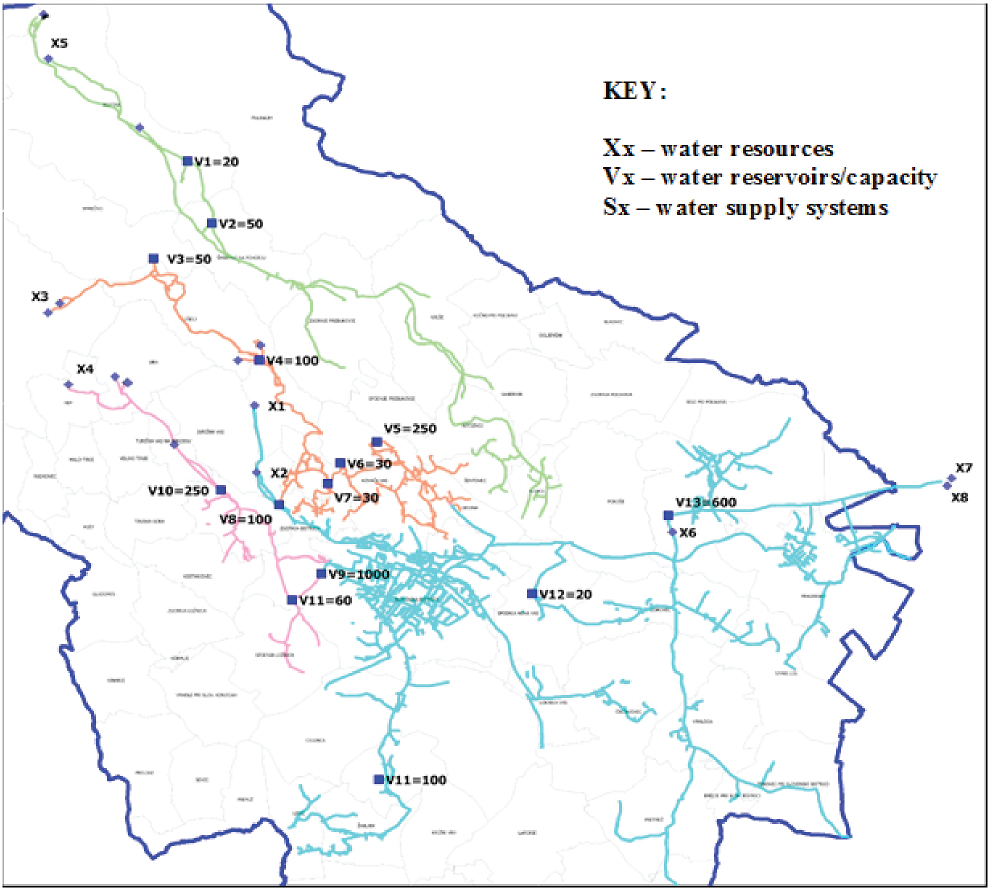



***Figure 1:*** *The positional scheme of water resources and water reservoirs*

## 2.2 The characteristics and influential factors of individual water resources

X1 – water supply [494 MASL]: It is situated directly above the channel of the Bistrica River. The aquifer is located in the interstitial zone, which is composed of granodiorite. Its size is impossible to determine. On the average, about 18 l/s of groundwater are extracted from the water supply eight months of the year and 10 l/s of water during the summer months. The body of water from which the groundwater is extracted (together with the water supply) is threatened primarily by the point sources of pollution due to the insufficient thickness of unsaturated zone. The point sources of pollution are spillages and illegal dumping sites that might arise in the area of the water supply. Contamination could also be caused by the ingress of the nearby stream directly into the water supply. The deterioration of the water quality can be effectively avoided if the water protection zones are strictly complied with. The water supply is carried out by gravity; therefore, consumption is limited only to the maintenance of the quality of the water source and the preventive disinfection of the system with NaOCl. Reconstruction activities in the coming years would be limited to the reconstructions of construction works. The conditions for the reconstruction are the favourable location of the water source and the total energy use enabled by connecting the system to the central water supply system. On the water source itself, it is obligatory to provide disinfection of drinking water and to enable the residual effect of disinfection. The measurements of the production of the water resource, which are dependent on weather conditions and natural resources, should be performed [8] [9] [11].

X2 – water supply [381.9 MASL]: It is located on a stream of the Bistrica The body of water is the surface water of the stream and is almost entirely supplied from rainfall and to a lesser extent from the infiltration of groundwater from the thick layer of weathering that occurs above primary magmatic-metamorphic stones. The length of the stream from its source to the mouth is 18.8 km, and 10.8 km from the source to the water supply. The hydrographic area occupies a narrow part of the southern slopes of Pohorje around the valley with an area of 32.41 km². At the X2 water supply, a maximum of 50 l/s of water is extracted during the rainy season and 25 l/s during the dry season. The greater part of the stream's surface is the part of a protected area, which forms part of Natura 2000. In addition, the water source is considered a partly natural watercourse for the better part of its current. Due to the large water flow in the water body, the quantities of collected water are acceptable and do not affect the ecological status of the body of water itself. The body of water is largely compromised of the following conditions: the scattered point sources of pollution that are represented by the agricultural areas within the basin of the stream Bistrica, the point sources of pollution, which are found primarily in the wild dumping sites, and various buildings with unregulated sewers and other interventions that alter the natural sensitivity of the body of water. In order to be able to evaluate the threat parameters, it is necessary to implement an AOP procedure for the preparation of drinking water in the system itself. The procedure is energy consuming. Moreover, the preparation of water is the least economically viable due to the use of chemicals and the obligatory presence of the work force.

Two pumps with characteristics Q = 50 l/s, P = 45 kW, which are necessary for the cleaning of UF filters in the return washing of the biological films of membranes, should be installed in the system [8] [9] [11].

X3 – water supply [880 MASL]: The surrounding area is mostly overgrown with mixed forest. These areas are dominated by extensive agriculture and forestry. The body of water is located in weathered layers of igneous Pluto granodiorite. The surface of the body of water is estimated at 0.153 km²; the average thickness of the aquifer's weathered cover is several meters. The water from the water supply is extracted by using the dredged shaft. On average, about 2 l/s of groundwater is extracted from the water supply. The body of water from which the groundwater is extracted together with the water supply is threatened primarily by the point sources of pollution due to the insufficient thickness of the unsaturated zone. The point sources of pollution could be, for example, farms directly above the water supply or the fuel spillage on the road over the water supply as well as the unfavourable weather conditions. On the water source itself, it is obligatory to provide disinfection of drinking water and to enable the residual effect of disinfection. It is necessary to perform the measurements of the production of the water resource, which is dependent on weather conditions and natural resources. The water supplies X4 and X5 are under the same potential threat [8] [9] [11].

X4 – water supply [880 MASL]: It is located on the eastern slopes of Pohorje. Its body of water is located in the thick weathered layer, which can be found above the metamorphic-magmatic rocks of Pohorje. The aquifer's surface is estimated at 857,400 m² (0.8 km²); the average thickness of the aquifer’s weathered cover is several tens of meters. In the rainy season, approximately 2.5 l/s of water is covered by the water supply whereas in dry periods up to 1.5 l/s of water is [8] [9] [11].

X5 – water supply [1289, 5 MASL]: On the eastern slopes of Pohorje, this water supply is located in the thick weathered layer, which is found above the metamorphic-magmatic rocks of Pohorje. The aquifer’s surface is estimated at 1.1 $km^2$, the average thickness of the aquifer’s weathered cover amounts to a several tens of meters. In the water supply, there is a maximum of 3 l/s of groundwater included [8] [9] [11].

X6 – borehole (deep well) [289.1 MASL]: It is located at the crest of the hill. The water is extracted from the Pliocene aquifer. The plio-quarternary regional aquifer occupies the eastern fringes of Pohorje between Maribor and Slovenska Bistrica, where it continues over the region of Dravinjske gorice and reaches the west all the way up to Ptujska gora. In the central part, it is covered by gravelly clay layers of the Drava River and its tributaries. The estimated area of the body of water is 1.1 $km^2$, the average thickness is around 40 m, and its volume is thus about 44,403,000 $m^3$. Preferred pumping quantities are up to 22 l/s. The microbiological water source is not compromised due to the thickness of the impermeable layer and due to the permeability of the earth layers in the aquifer zone. The bigger problem is the concentration of iron and manganese, which have the geological origin in the aquifer zone itself. The production of drinking water according to AOP processes should be anticipated. Allowed concentrations could be provided with regular flushing and cleaning of wells as well as by mixing the water from different supply systems. The replacement of existing pumps with three pumps with following characteristics of Q = 150 $m^3$/h, p = 4-10 bar, N = 37 kW, 380V is anticipated. The movement of the measuring point on the TP is also anticipated. The tariff billing system would thus be lowered by one degree, and extraction characteristics would be adjusted to the period of reduced energy consumption in order to avoid the conical consumption of electricity[8] [9] [11].

X7 – borehole (surface well) [246.2 MASL]: Located at the top gravel terrace on the Drava field, this body of water occupies large areas, and it is impossible to define it locally. It is composed of three aquifers. On the regional level, it occupies the eastern fringes of Pohorje all the way up to Ptujska gora. In the central part, it is covered by gravelly clay layers of the Drava River and its tributaries. Its area is estimated at 429.3 $km^2$, with its depth sometimes exceeding 1000 m. The estimated total abstraction from wells is about 80 l/s of water. The body of water from which together with the water supply the groundwater is extracted is threatened due to the fact that it lies relatively shallow under the surface and is separated from the surface by a permeable layer and only locally by a thick layer of clay. It is threatened by agriculture, industry, septic tanks and un-repaired gravel pits. The borehole is heavily contaminated with triazine pesticides, nitrates and herbicides. It is necessary to ensure the disinfection of drinking water and provide adequate amounts of water from the deeper layers of the aquifer. Two pumps with characteristics Q = 43 l/sec, H = 90 m, P = 50 kW are built into the system [8] [9] [11].

X8 – borehole (deep well) [246.2 MASL]: Located at the highest gravel terrace in the Drava field, this plio-quarternary regional aquifer occupies the eastern fringes of Pohorje all the way up to Ptujska gora. In the central part, it is covered by gravelly clay layers of the Drava River and its tributaries. The estimated area of the body of water is 2.5 $km^2$, the average thickness is around 54 m, and its volume is thus about 121,655,250 $m^3$. The recommended pumping quantities from the wells are 28 l/s. The water source is under the same threat as X6. Two-pumps with characteristics Q = 15 l/s and H = 100 m, P = 37 kW-X8 should be fitted into the system [8] [9] [11].

## 2.3 The required quality of water resources

The requirements concerning the content of the parameters in drinking water are determined by the Rules on Drinking Water (The Official Gazette of the Republic of Slovenia, no. 19/04, as amended). Table 1 lists the most basic parameters in terms of the specific characteristics of individual water resources, which limit their direct use without prior preparation [4] [16].

## 2.4 The list of possible contaminants regarding the characteristics of water resources

***Table 1:*** *The list of the most distinctive contaminants according to the characteristics of the water source and the level of threat*

| **Possible contamination** | **The description of the contamination** | **Limit values** | **Threats to the water source** |
|---|---|---|---|
| Coliform bacteria | The group of bacteria that can be found both in the human and animal waste and in the environment. | 0/100 ml | X1, X2, X3, X4, X5, X7 |
| Escherichia coli | The bacteria are the indicator of pollution by faeces. | 0/100 ml | X1, X2, X3, X4, X5, X7 |
| Enterococci | The bacteria are the cause of an older faecal contamination. | 0/100 ml | X1, X2, X3, X4, X5, X7 |
| Clostridium sporogenes | Sporogenes present in the surface waters. | 0/100 ml | X2 |
| Triazine pesticides | Atrazine is an organic herbicide used in agriculture for weed control. | 0.1 µg/l | X7 |
| Herbicides | Metolachlor is an herbicide used in agriculture. | 0.1 µg/l | X7 |
| Nitrates / nitrites | Nitrates ($NO_3$) and nitrites (NO2) occur when the fertilizers are applied. | 50 mg/l/ 0.50 mg/l | X7 |
| Mn | It primarily represents an aesthetic problem. | 50 µg/l | X6, X8 |
| Fe | The presence of iron in the water affects its flavour, colour and aroma. | 200 µg/l | X6, X8 |

The table shows that the source X7 is the critical source of the drinking water supply since its quality of drinking water is questionable in almost all points of potential contaminants. Nevertheless, it has a massive advantage over the other water sources due to the capacity of the production of the water resource. Precisely due to the assessment of the risk level in the process of optimizing the system, the idea of replacing the water source or of protecting its qualities has arisen.

# 3 OPTIMIZATION OF THE WATER SUPPLY SYSTEM

## 3.1 The organisation chart of the state of development of the water supply system

Due to the lack of water capacities and the inadequate hydraulic design of the water supply network, it is necessary to approach the hydraulic improvement of the entire system effectively and meaningfully as well as to ensure the quality of drinking water in accordance with the legislation currently in force. The system of improving the overall water supply network would take place in phases. The system of energy improvement is to be divided into four phases.

Figure 2 shows the estimated construction of the energy-efficient water system in phases and describes the activities that would be needed to ensure the optimal operation of the water supply system, which directly affects the economically justified price of water services for users.

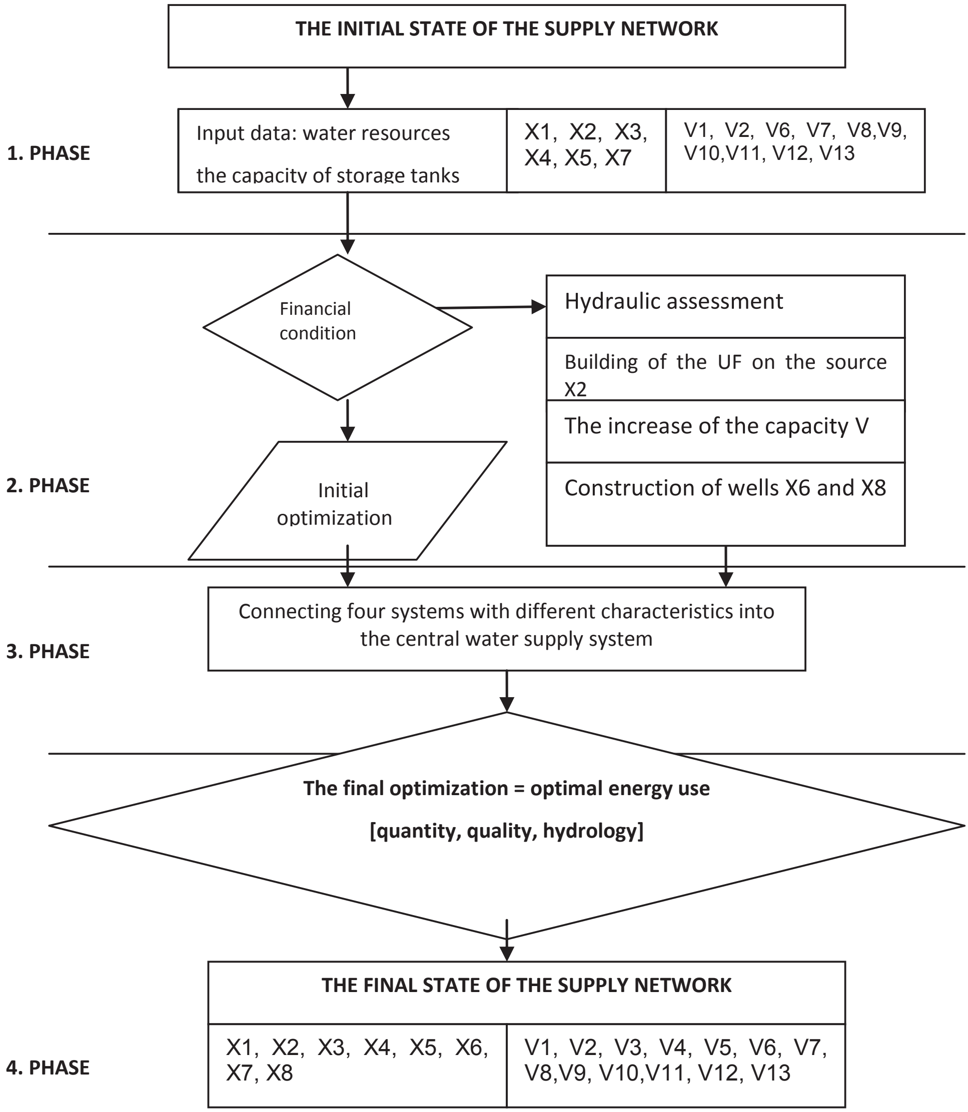



***Figure 2:*** *The organization chart of the phased processes of work*

## 3.2 The phases of the optimization process

Phase 1: A thorough review of the system was made and the water quality at a particular water source determined. The primary task of the first phase was the determination to provide sufficient quantities of water resources at the relevant quality level and the selection of the cleaning procedures for the existing water resources given the available technical options and resources. The procedures were prepared on the theoretical basis of the review and the assessment of the existing water supply system and on the basis of the evaluation of conditions and opportunities for the modernization of the system in accordance with the boundary conditions of the quantitative status of water resources, the required quality of water by the user and optimal energy state of the water-supply areas [14] [15].

Phase 2: This phase is divided into four steps. In the first step, the calculation of the hydraulic assessment of the stability and functioning of the water supply system was made. Based on the results, the possibilities for the reconstruction of infrastructure and the purifying of the drinking water by advanced methods were verified. The possibilities of water regulation in terms of energy efficiency by upgrading water storage tanks were examined.

The second step required the construction of deep wells, X6 and X8, which provides the quality and the quantitative boundary condition(mixing of water from wells X6 and X8 with other individual water resources X2, X7) which can also meet the quality conditions if there is appropriate mixing of water.

The third step was achieving the condition of water quality, taking into account the given characteristics of the water source X2 and the available technology. The ultrafiltration procedure enabled doing so. The ultrafiltration technique is membrane filtration-driven by the external differential pressure. In addition to the differential pressure, differences in concentration occur during the process. In the case of electrically charged particles, an electric field also occurs. The membranes shown in Figure 3 are hollow tubes with an internal diameter of approximately 0.8 mm and a porous wall. The pore size is about 20 nm (0.020 micrometres), which means that it may retain bacteria (6 log grades) and viruses (4 log grades). Membrane tubes are grouped into membrane elements which are inserted into the pressure tube [12] [13] [17] [20].

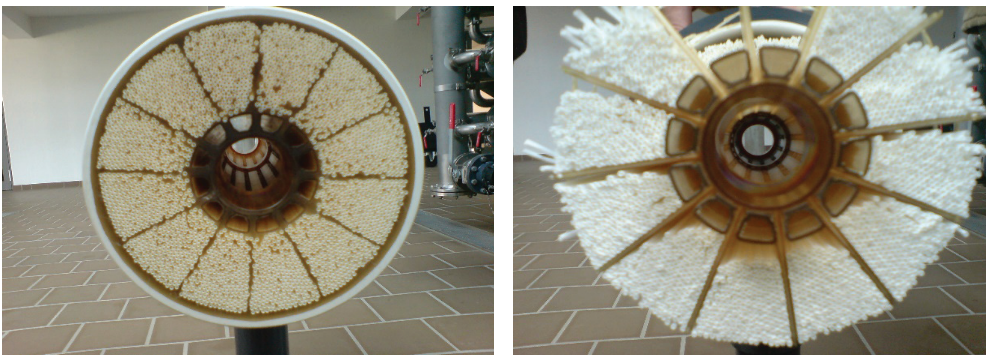


***Figure 3:*** *The picture of the membrane module*

The forth step of Phase 2 of the system's optimization process is the assessment of the available capacities of water reservoirs forming part of the individual water supply system. The capacities of water reservoirs do not currently meet the needs for the retention of sufficient quantities of drinking water in terms of the inflows, fire water and the availability of water resources. As a result, the individual systems suffer significant losses of the water already extracted from the system. In the course of the phased construction and the optimization of the water supply system, the construction works for increasing water storage tanks in accordance with Table 2, for the individual water supply systems are being done [5].

***Table 2:*** *The capacity of water reservoirs in individual systems*

| **Water supply system** | **The existing capacity of the water reservoirs** | **The expected capacity of water reservoirs** |
|---|---:|---:|
| S1 | 1800 m³ | 4700 m³ |
| S2 | 460 m³ | 460 m³ |
| S3 | 70 m³ | 270 m³ |
| S4 | 310 m³ | 310 m³ |

The need for the integration of individual systems into a single water supply system is, therefore, the inevitable task of the stakeholders responsible for the management and maintenance of the water supply system. Their task should be to establish an energy-efficient system in order to minimize losses of the water extracted from the system.

Phase 3: The essence of the hydraulic improvements and assessment of the geographical terrain is the functional interconnection of water supply systems into the central water supply system. After reviewing the elevation angles and the geographical terrain shown in Table 3, it is obvious that the interconnection of all four systems is possible and with this measure the quantitative exchange of water is provided even in spite of unfavourable hydrological deficits, [10].

**Table 3:** The geographic relief of the connections of the water supply system

| **Water supply system** | **Definition V/n.v.** | | | | | | **The connection option** |
|---|---|---|---|---|---|---|---|
| S1 | **V8** | 345.4 | **V12** | 307 | | | YES |
| | **V9** | 328 | **V13** | 298.5 | | | |
| S2 | **V3** | 853.1 | **V5** | 467.3 | **V7** | 470.6 | YES |
| | **V4** | 651.6 | **V6** | 463.1 | | | |
| S3 | **V1** | 907.5 | **V2** | 842.6 | | | YES |
| S4 | **V10** | 543.5 | **V11** | 319.2 | | | YES |

Phase 4: The final optimization of the water supply system is planned as well as the ensuring of the control and the functioning of the system with the use of a numerical model based on the quantities, required quality of the water sources, and weather conditions. The control and the functioning of the system is ensured with the introduction of on-line measuring of the quality of water sources as well as with the upgrading and optimizing the telemetric management of the water supply telemetry system to such a degree that with minimum energy consumption, the optimal quality of drinking water would be provided in accordance with the current hydrologic conditions. From the perspective of optimization, the possibility of producing one's own energy is considered. The energy would be used for providing illumination and for the ability to provide one's own energy for the purposes of providing

quality condition of surface water sources. The construction of a small hydropower plant under the given conditions should be incorporated into the supply system [1][2].

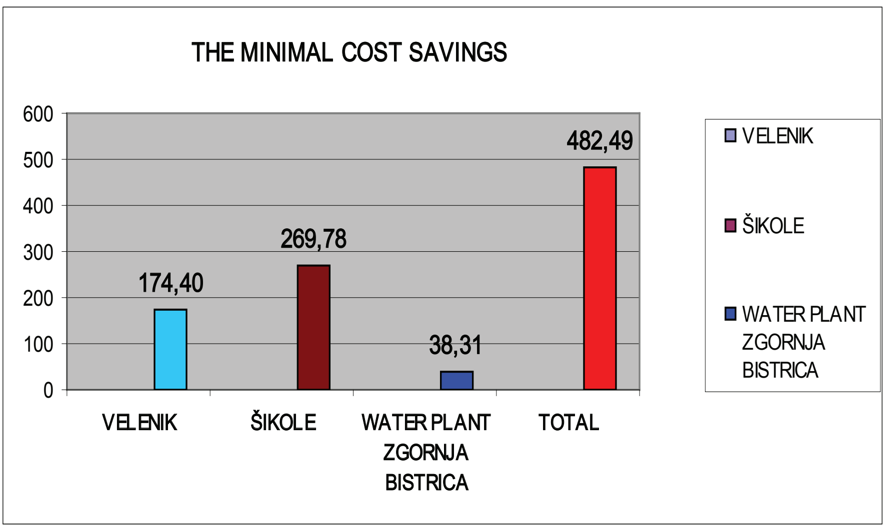
# 4 THE INFLUENCE OF SPECIFIC INDIVIDUAL PARAMETERS ON THE OPTIMIZATION

## 4.1 The optimization of the system in terms of energy consumption

All water sources are replenished in good operating conditions of the water storage capacity of 1700 $m^3$. With the completion of the works in the process of the construction of water supply facilities as part of the cohesion project for the construction of the water supply system for drinking water and with the increase of the capacity of water storage tanks from 1800 $m^3$ to 4700 $m^3$, as well as with the introduction of the basic pumping conditions in a lower tariff system and by avoiding peak energy consumptions, there would be a significant reduction in power consumption achieved; simultaneously, the tariff system for the energy consumption would be modified. By modifying the energy consumption, the monthly savings would be equal to the amount shown in the following table, at least in the case of more favourable operating conditions even up to one third of the calculated and displayed amount due to the conical charge of the energy consumption [3] [7].

***Table 4:*** *Possible energy savings in energy consumable water resources*

| | | | |
|---|---|---|---|
| **VELENIK** | | | **174.40 €** |
| 64 | 4.02497 | 257.60 | |
| 64 | 3.09094 | 197.82 | |
| 64 | 1.79098 | 114.62 | |
| 0 | 1.79098 | 0,00 | |
| **ŠIKOLE** | | | **269.78 €** |
| 99 | 4.02497 | 398.47 | |
| 99 | 3.09094 | 306.00 | |
| 99 | 1.79098 | 177.31 | |
| 0 | 1.79098 | 0,00 | |
| **WATER PLANT ZGORNJA BISTRICA** | | | **38.31 €** |
| 22 | 4.83229 | 106.31 | |
| 22 | 3.09094 | 68.00 | |
| | | **TOTAL** | **482.49 €** |
| | | **TOTAL/12** | **5,789.84 €** |

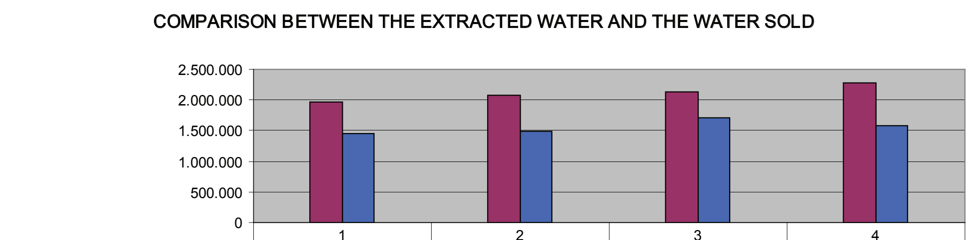


## 4.2 The influence of disruptions in the water supply system on the optimization

The hydraulic connection of water supply systems into a single supply system would completely prevent the water loss in the system. Providing hydro-geologically favourable conditions, in the case of the connection of the system, the maximum allowed limit of the utilization of water resources with the lowest operating costs would be reached. Together with that and with the complementing of the quantities of less favourable water resources in terms of energy use, a system of optimal functioning in terms of technical and financial characteristics would be established. The possibility of connection was already defined in Table 3 and geographically shown in Figure 7. By connecting water systems, the losses of the already extracted water in the system would be reduced since, with the increase of water storage tanks and with the telemetric balance of water extraction, the surpluses of the already extracted water in the water distribution network would be intercepted.

The significant disruptions in the operation of the water system are mainly caused by exceeding allowed values for the parameters of drinking water quality at a specific water source, regarding the characteristics of the water source. Moreover, the disruptions in the system of drinking water supply can easily occur due to unforeseen events in the course of eliminating the defects in the water supply system. These kinds of disruptions are short-term and they affect the losses in the system only to a lesser extent. The greatest losses in the water supply system occur when there are undetected hidden defects in the distribution system of drinking water supply and unauthorized water abstraction from the system. These problems should be solved in phases, but not in the course of this project. Table 5 shows the problems of quantitative losses of water from the water supply system in question [2] [10] [17].

***Table 5:*** *Water losses in the system*




| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| YEAR | 2010 | 2011 | 2012 | 2013 |
| The quantity of the extracted water | 1.962.749 | 2.075.816 | 2.131.840 | 2.272.956 |
| The quantity of the water sold | 1.446.669 | 1.493.006 | 1.710.245 | 1.583.721 |
| LOSSES | 26% | 28% | 20% | 30% |

## 4.3 The impact of the specific costs on the optimization

Depending on the characteristics, operating and maintenance conditions and energy use, the price of a cubic metre of water can be easily determined for the individual water sources. Table 6 shows the calculation of the price of water per cubic meter depending on the individual characteristics of the water source. According to the on-line measurement of the quality of the water sources, and according to the available quantities and specific costs, the optimal regulation of water supply is planed [19].

***Table 6:*** *The average price of water based on the characteristics of the water source*

| The name of the drinking water source | The amount of the water abstracted 2014 | The energy consumption | The work costs | The cost of chemicals | Other costs | Total costs | Price per unit | Price per unit |
|---|---|---|---|---|---|---|---|---|
| X1 | 551,129 | 1,500 € | 30,000 € | 4,000 € | 5,000 € | 40,500 € | 0.0735 € | 0.0955 € |
| X2 | 355,854 | 17,000 € | 110,000 € | 28,000 € | 25,000 € | 180,000 € | 0.5058 € | 0.6576 € |
| X3 | 115,484 | 2,636 € | 20,000 € | 2,000 € | 8,000 € | 32,636 € | 0.2826 € | 0.3674 € |
| X4 | 69,107 | 830 € | 18,000 € | 4,000 € | 8,000 € | 30,830 € | 0.4461 € | 0.5800 € |
| X5 | 168,750 | 100 € | 36,000 € | 2,000 € | 12,000 € | 50,100 € | 0.2969 € | 0.3860 € |
| X6 | 132,132 | 11,600 € | 21,000 € | 2,000 € | 12,000 € | 46,600 € | 0.3527 € | 0.4585 € |
| X7, X8 | 445,632 | 30,000 € | 42,000 € | 5,000 € | 20,000 € | 97,000 € | 0.2177 € | 0.2830 € |
| | | | | | | | **Average price:** | 0,4040 € |

In terms of quantity, in accordance with Table 6, it is, therefore, reasonable to exploit the water source with the lowest economic value, as shown in Figure 4, and the highest level of quality and production of the water source, as shown in Figure 5.

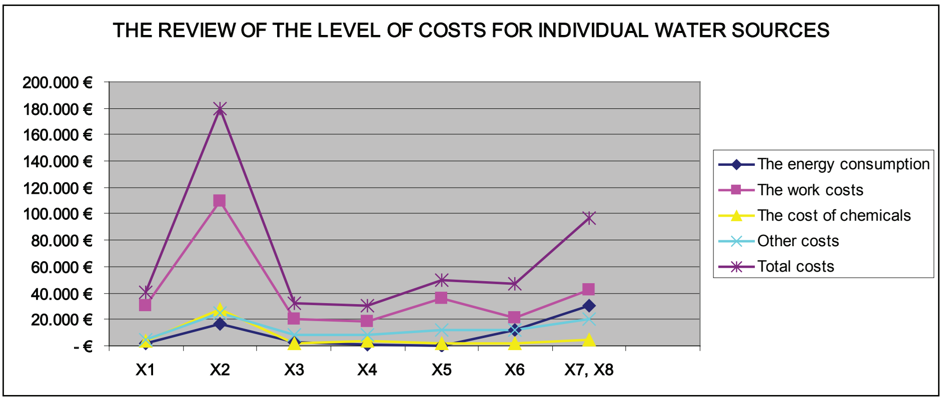



***Figure 4:*** *The assessment of the costs for the individual water sources*


***Figure 5****: The comparison of the costs and the production of the water source*

## 4.4 The influence of the capacity of water sources on the optimization

The quantities of the abstracted water in the water supply system are dependent on the technical characteristics of the individual water source, the need for the quantities of extracted water and the natural features of the available capacities of the water source. The allowed quantities of drinking water extracted from the system are noted in the water-related licenses based on the calculated and measured values of the available capacities of the individual aquifer taking into account the ecological minimum of the aquifer's area. Table 7 gives an overview of the quantities of the water in the water supply system which are lower than the permitted levels in water licenses, which is why the optimization is wide open, [18].

***Table 7:*** *The capacity of water sources and the amount of the extracted water*

| The name of the drinking water source | The amount of the withdrawal of VD [m³] | The amount of the extracted water, 2011 | The amount of the extracted water, 2012 | The amount of the extracted water, 2013 | The amount of the extracted water, 2014 |
|---|---|---|---|---|---|
| X1 | 580,000 | 203,539 | 343,122 | 367,172 | 551,129 |
| X2 | 1,350,000 | 742,639 | 785,375 | 625,891 | 355,854 |
| X3 | 137,000 | 44,910 | 61,666 | 92,329 | 115,484 |
| X4 | 103,500 | 49,857 | 52,252 | 75,548 | 69,107 |
| X5 | 170,000 | 33,023 | 38,050 | 113,612 | 168,750 |
| X6 | 300,000 | 237,488 | 180,144 | 116,244 | 132,132 |
| X7 | 1,396,719 | 292,340 | 302,920 | 280,120 | 249,870 |
| X8 | | 243,790 | 212,440 | 182,090 | 157,970 |

Figure 6 shows the trend of the optimal utilization of water sources in accordance with the required boundary conditions of quality, quantity and price. After the connections of the water supply systems are made in accordance with the proposed final state shown in Figure 7, the highest level of optimization of the system would be reached.

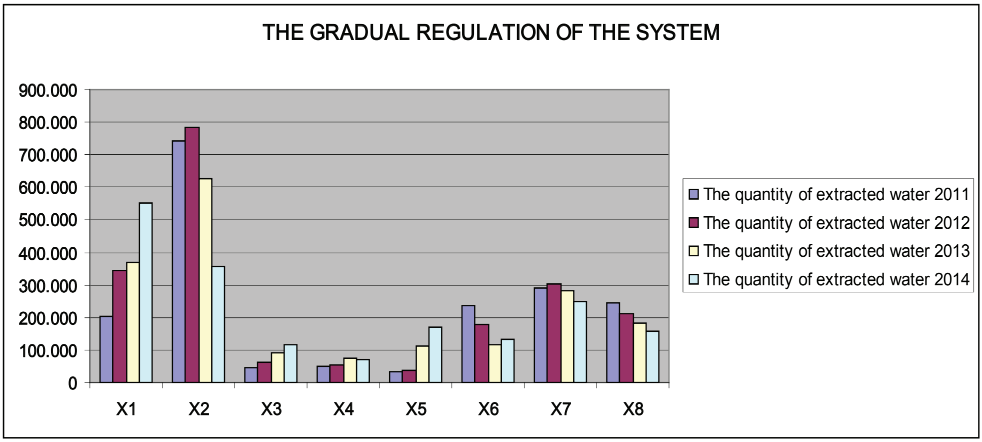



***Figure 6**: The trend of the utilization of water resources*

## 5 CONCLUSION

Since the economic exploitation of water resources represents savings in the consumption of the capacities of water resources for an entire generation and thus reduced energy consumption, it is more than reasonable to perform the optimization of the entire water supply system, taking into account all the given aspects.

Figure 7 shows the final state of the water supply system after all four phases of the optimization are performed. In the case that the capacities of storage tanks are upgraded and with them associated improvements of the hydraulic system made, providing the favourable hydrological conditions and the possibility of the quantitative utilization of water sources of the gravitational system as well as the water refilling from the unfavourable water sources in terms of energy consumption but simultaneously quantitatively independent of the hydrological conditions, the telemetric monitoring of the system status could be reached. The level of monitoring would be such that it would provide the highest possible rational supply with drinking water in terms of quantity, quality and price to satisfied customers.

The potential energy utilization of water sources within the water supply system and online control with the use of an appropriate numerical model simulation of the entire water supply system, which is currently under preparation, contributes to the optimal use of water resources and to the required energy consumption.


***Figure 7:*** *The final state of the water supply system*

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# 1 MAIN CHAPTER

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## 1.1 Section

**(Arial bold, 11pt, after paragraph 6pt space)**

### 1.1.1 Sub-section

**(Arial bold, 10pt, after paragraph 6pt space)**

Example of Equation (lined 2 cm from left margin, equation number in normal brackets (section. equation number), lined right margin, paragraph space 6pt before in after line):

Equation (1.1)

Tables should have a legend that includes the title of the table at the top of the table. Each table should be cited in the text.

Table legend example:

***Table 1:*** *Name of the table (centred, on top of the table)*

Figures and images should be labelled sequentially numbered (Arabic numbers) and cited in the text – Fig.1 or Figure 1. The legend should be below the image, picture, photo or drawing.

Figure legend example:

***Figure 1:*** *Name of the figure (centred, on bottom of figure, photo, or drawing)*

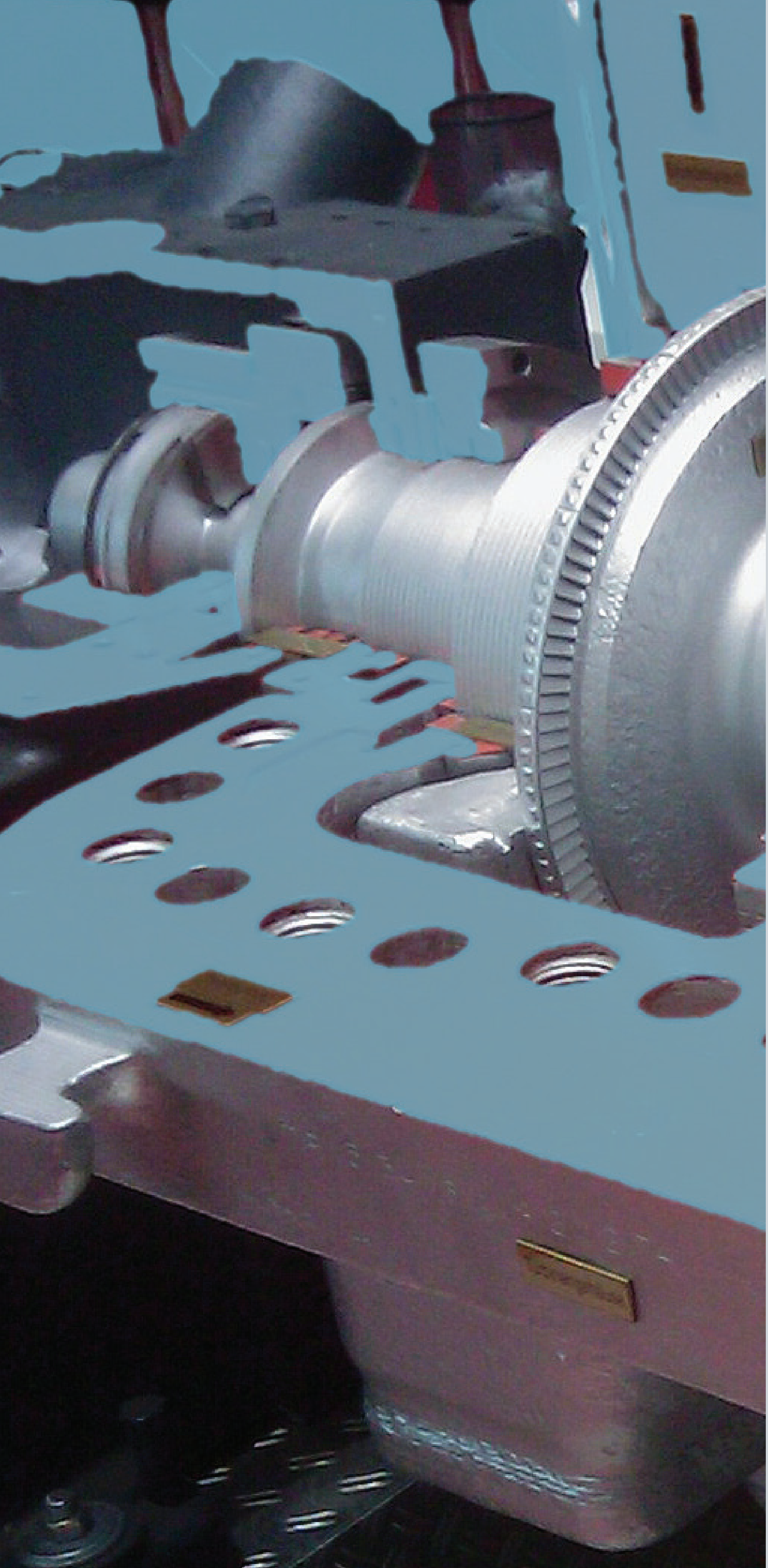
## References

[1] **Name. Surname:** *Title,* Publisher, p.p., Year of Publication

Example of reference-1 citation: In text, *Predin, [1],* text continue. **(Reference number order!)**

## Nomenclature

| | |
|---|---|
| **(Symbols)** | (Symbol meaning) |
| $t$ | time |



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