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Geotermalna energija je v nekaterih državah sveta zelo pomemben obnovljiv vir energije za proizvodnjo električne in toplotne energije. Zloženka geotermalna energija izhaja iz dveh grških besed in sicer geo (Zemlja) in therme (toplota). Lahko bi jo tolmačili tudi kot Zemljina toplotna energija. Je obnovljivi vir energije, katerega bi lahko v Sloveniji učinkoviteje izkoriščali, saj so na posameznih območjih temperature na globini 500 - 4000 m zanimive za potencialno izrabo.

V grobem lahko delimo geotermalne vire na nizkoentalpijske (pod 150 ºC) in visokoentalpijske geotermalne vire (nad 150 ºC). Seveda se tudi nizkoentalpijski viri lahko razlikujejo glede temperaturnih nivojev. Nizkoentalpijske geotermalne vire v svetu večinoma uporabljajo za daljinsko ogrevanje hiš in zimskih vrtov ter v zdraviliščih. Za dolgoročno izkoriščanje geotermalnih virov je zelo pomembno vračanje geotermalne vode nazaj v vodonosnik. Energijo Zemlje lahko izrabljamo tudi s pomočjo toplotnih črpalk in dodane električne energije. Obstajajo tudi poskusi uporabe nizkoenetalpijskih virov v povezavi z drugimi viri toplotne energije, za soproizvodnjo toplotne in električne energije. Izdatnejša uporaba izkoriščanja geotermalne energije bi lahko pripomogla k zmanjšanju izpustov toplogrednih plinov in večjemu zaposlovanju v zelenih tehnologijah.

Jurij AVSEC
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Dear Readers of the Journal of Energy Technology (JET)

The utilization of geothermal energy in some countries of the world demonstrates a critical renewable energy source for electricity and heat production. The word “geothermal” comes from two Greek words: geo (meaning Earth) and therme (heat); it could be translated as “heat of”. It is a renewable energy source, which could be much more efficiently exploited in Slovenia, where there are some areas with temperatures at a depth of 500 – 4000 m that show interesting potential.

Geothermal resources can roughly be divided into low-enthalpy (below 150 ºC) and high-enthalpy resources (above 150 ºC). Of course, low-enthalpy sources may vary according to temperature levels, and they are mostly used for the district heating of houses, winter gardens and for use in spas. Very important for the long-term exploitation of geothermal sources is the reinjection of geothermal water back into the aquifer. The geothermal energy could be exploited also with the help of heat pumps and added electricity. There are also attempts to use low-enthalpy sources in conjunction with other sources of heat for the combined production of heat and electric power. Abundant use of geothermal energy could contribute to reducing greenhouse gas emissions and increasing employment in green technologies.

Jurij AVSEC
Editor-in-chief of JET

Table of Contents / Kazalo

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THE EXPLOITATION OF ULTRA-LOW-ENTHALPY GEOTHERMAL ENERGY IN AN ORC PROCESS IN COMBINATION WITH RES AND A HEAT PUMP

IZKORIŠČANJE ZELO NIZKOENTALPIJSKE GEOTERMALNE ENERGIJE V ORC PROCESU V KOMBINACIJI Z OVE IN S TOPLOTNO ČRPALKO

Urška Novosel[ℜ], Jurij Avsec[1], Ivana Tršelič[2], Sonja Novak[3]

Keywords: renewable energy resources, ORC process, energy analysis, economic analysis

Abstract

The paper presents a model of a binary-cycle hybrid power plant to be located in Topolšica, Šalek Valley, Slovenia. It is based on an ORC process and utilises several different renewable energy sources: geothermal energy, solar energy, and wood biomass energy. The portion of geothermal energy is so low that it is used in the system as a source of energy for a heat pump, thus increasing the inlet temperature of the ORC process. The model of the hybrid ORC power plant dealt with in this paper is intended only for electricity production.

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The energy source used first is geothermal water from a well, entering the heat pump to heat the heat pump working medium. Solar energy and wood biomass energy are sources of heat flow, additionally heating the ORC process working medium. The paper presents thermodynamic and economic analyses of this potential system.

Povzetek

Članek predstavlja model binarne hibridne elektrarne, ki bi bila postavljena v Topolšico, Šaleška dolina, Slovenija. Osnova je ORC proces, ki uporablja več različnih obnovljivih virov energije – geotermalno energijo, sončno energijo in energijo lesne biomase. Delež geotermalne energije je tako nizek, da jo v sistemu uporabimo kot vir energije za uporabo v toplotni črpalki in tako povečamo vstopno temperaturo v ORC proces. Model hibridne ORC elektrarne v članku je predviden samo za proizvodnjo električne energije. Energetski vir, ki je najprej uporabljen, je geotermalna energija iz vrtine, ki vstopa v toplotno črpalko, kjer segreje delovni medij toplotne črpalke. Sončna energija in energija lesne biomase sta izvora toplotnega toka, ki še dodatno segrejeta delovni medij ORC procesa. V članku sta predstavljeni termodinamična in ekonomska analiza takšnega potencialnega sistema.

1 INTRODUCTION

Global warming is a current crucial issue in the world and requires immediate action in order to reduce it. New, clean power generation technologies have to be explored. One very good option is the exploitation of renewable energy sources using hybrid technologies.

The so-called binary processes to increase system efficiency by exploiting the maximum amount of energy are used for the exploitation of low-enthalpy geothermal energy. According to the principles of thermodynamics, geothermal binary cycle power plants are the closest to the conventional thermoelectric or nuclear plants in that they have the working medium in a closed cycle, *[1]*.

An organic Rankine process (ORC) was chosen as a geothermal power plant model, i.e. a binary process, similar to the Rankine vapour power cycle in terms of thermodynamics, except that hydrocarbons are used as the working medium in the ORC instead of vapour, *[2]*, reaching the boiling temperature sooner and, consequently, being more suitable for processes of power generation from low-temperature sources, *[3]*.

The working medium chosen on the basis of thermodynamic properties for a specific system receives heat, evaporates and expands through the turbine, and then it is condensed and returns to the evaporator with a supply pump, *[1]*.

2 SYSTEM DESCRIPTION AND STRUCTURE

The geothermal power plant model is essentially an ORC system, in which the working medium is heated by various RES. First, we exploit geothermal energy through a heat pump, then solar energy and finally wood biomass energy. Three different RES will be used for the system with the advantage being to utilise the available RES potential as much as possible. This will provide greater operational reliability of the system and, consequently, reduce the oscillation of electricity production. Figure 1 shows the heat pump/ORC system diagram with all its elements.

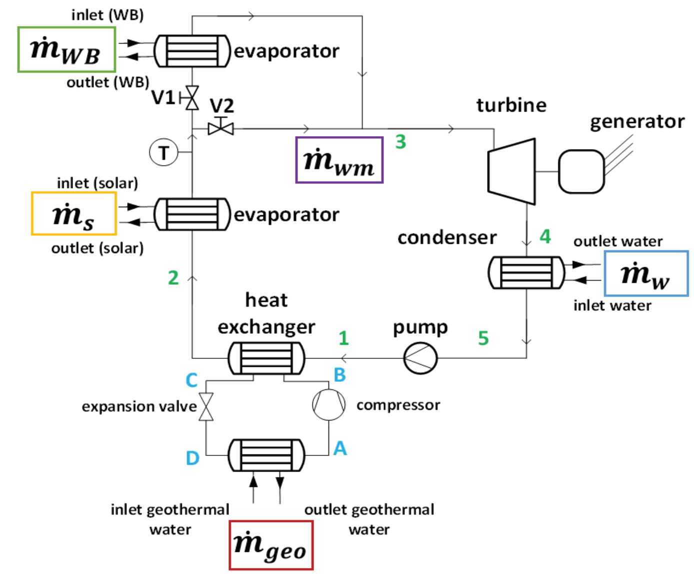

Figure 1: *Heat pump hybrid system diagram*

Geothermal energy enters the system as a medium that heats the heat pump medium in the heat pump evaporator. Then we look at the ORC process and see that in State 1 the working medium enters the heat exchanger, which is in fact a heat pump condenser, where it receives the heat from the heat pump working medium and passes to State 2. The working medium then enters the evaporator from State 2, where it is additionally heated by the heat from a solar subsystem. Immediately after this stage, a temperature sensor is placed in the system, which measures the temperature of the working medium. If the sensor detects a lower temperature than desired, valve V2 closes and valve V1 opens, thereby allowing the working medium to pass into another evaporator to be additionally heated by the heat from the wood biomass subsystem, where it is heated to the desired temperature, which is State 3. In State 3, the working medium enters the steam turbine, where it expands to State 4. The ORC process working medium then enters the condenser, where it releases the heat to the coolant, i.e. water in our case, and passes to State 5. In the last step of the cycle, the working medium passes through the pump from State 5 to State 1, *[4]*.

The correct working fluids must be chosen for both the ORC process and the heat pump, because the choice of the working fluid has a great impact on the efficiency of the processes. According to *[5],* R245fa is an optimum choice of the working medium. Considering its thermodynamic properties and environmental characteristics, it is suitable for a number of applications in industry, *[6].* R134a is chosen as the heat pump working medium, also widely used in similar processes, *[7].*

3 INPUT DATA AND DIAGRAMS

In system modelling, some parameters need to be defined, some are assumed and some are obtained from the data. The basis for the ORC process calculation is the p-h diagram in Figure 2, *[7],* showing the changes to the states of R245fa in the ORC process.

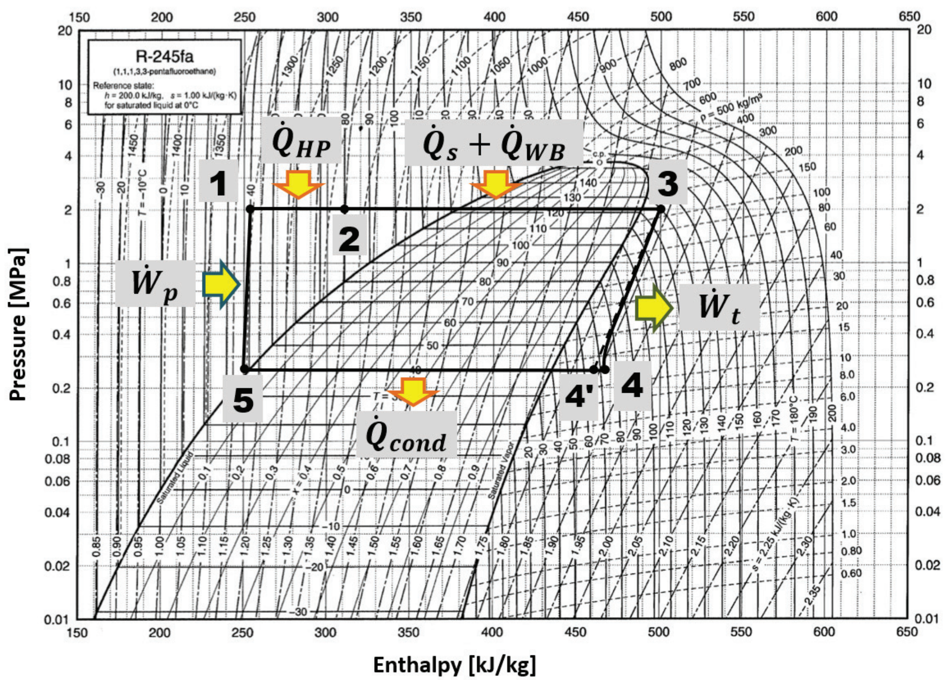

Figure 2: *p-h diagram R245fa*

The input data was provided by two geothermal wells in the area of Topolšica (Šalek Valley, Slovenia). The total average geothermal water flow from the two wells is 50 l/s and the maximum temperature 40 °C, *[8].* The collected input data for the ORC system is indicated in Table 1.

Table 1: *Data for the ORC system calculation*

Parameter	Value	Parameter	Value
$c_{p,w}$, $c_{p,geo}$	4.18 kJ/kgK	H	3.4 kWh/kg
G	1,250 kWh/m²	ΔT_{geo}	8 K
h_1	255 kJ/kg	ΔT_w	8 K
h_2	310 kJ/kg	$\dot{V}_{geo}$	50 l/s
h_3	500 kJ/kg	η_b , η_t	0.8
h_4	468 kJ/kg	ρ_{geo}	1,250 kg/m³
h_5	250 kJ/kg	ρ_{wm}	1,350 kg/m³

Before carrying out the ORC system calculation, the calculation of the heat pump has to be provided. The result of the heat pump calculation is used as the input data for the calculation of the ORC process indicated below.

The geothermal water temperature is too low to enter the ORC system and, therefore, it has to be heated. We decided to install a heat pump using R134a as a working medium. The Solvay program was used for the calculation of the heat pump performance. Table 2 contains the input parameters, output parameters, and results of the calculation. Figure 3 illustrates the p-h diagram of the heat pump, *[7].*

Table 2: *Heat pump parameters*

Element, parameter	Value
Evaporator	T = 30 °C, superheating 5 K, $\dot{Q}_{geo}$ = 2,090 kW
Condenser	T = 90 °C, subcooling 0 K, $\dot{Q}_{HP}$ = 3,040 kW
R134a mass flow	$\dot{m}_{R134a}$ = 27.22 kg/s
Point A (see Figure 3)	p = 7.7 bar, T = 35 °C, h = 419.88 kJ/kg, s = 1.7311 kJ/kgK
Point B (see Figure 3)	p = 32.44 bar, T = 104.33 °C, h = 454.52 kJ/kg, s = 1.7449 kJ/kgK
Point C (see Figure 3)	p = 32.44 bar, T = 90 °C, h = 343.08 kJ/kg, s = 1.4391 kJ/kgK
Point D (see Figure 3)	p = 7.7 bar, T = 30 °C, h = 343.08 kJ/kg, s = 1.4775 kJ/kgK
Compressor efficiency	85%
Compressor power	$\dot{W}_{HP}$ = 943 kW

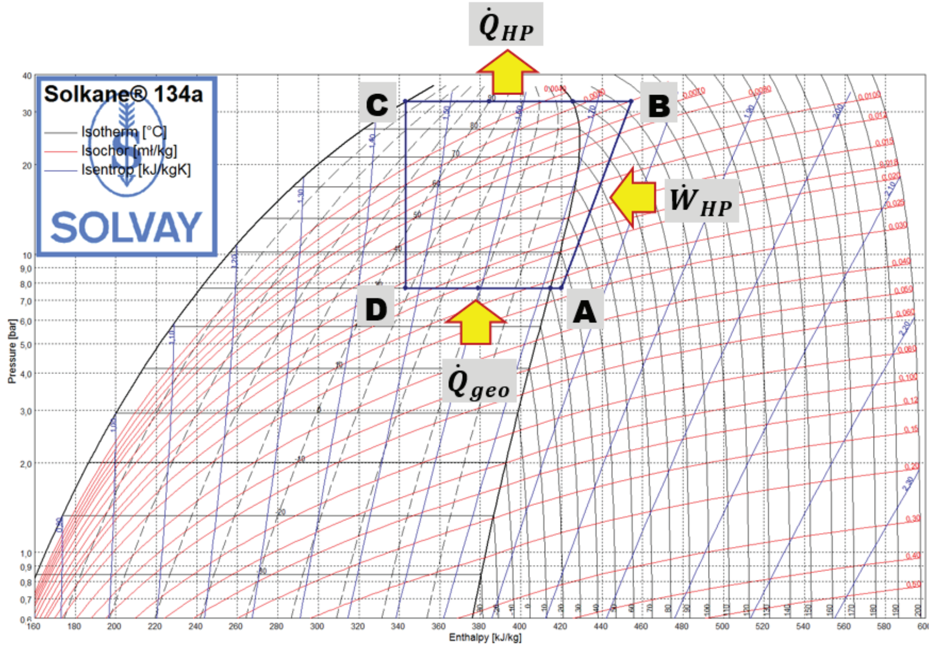

Figure 3: *p-h diagram R134a*

4 THERMODYNAMIC AND ECONOMIC CALCULATION

The following equation was used to calculate the geothermal water heat flow:

$$\dot{Q}_{geo} = \dot{V}_{geo} \cdot \rho_{geo} \cdot c_{p,geo} \cdot \Delta T_{geo} \tag{4.1}$$

This heat flow enters the heat pump in order to heat R134a in the heat pump evaporator and R134a then heats R245fa (see Figure 1). Examining the diagram in Figure 2, we calculated how much heat flow was required from the heat pump working medium to change State 1 to State 2. For further calculation, Equation 4.2 is used:

$$\dot{Q}_{HP} = \dot{Q}_{wm} \tag{4.2}$$

It was assumed that the total heat flow was transferred to the R245fa working medium – heat exchangers have the efficiency of 100%. Equation 4.3 is used to calculate the working medium mass flow.

$$\dot{m}_{wm} = \frac{\dot{Q}_{wm}}{h_2 - h_5} \tag{4.3}$$

In the next step, we will calculate how much additional heat flow is required to heat R245fa to the desired 130 °C (see Figure 2). The additional heat flow is divided into two components: the heat flow from the solar subsystem and the heat flow from the wood biomass subsystem, as can be described by Equation 4.4:

$$\dot{Q}_{add} = \dot{Q}_s + \dot{Q}_{WB} \tag{4.4}$$

The value of the additional heat flow to reach State 3 (see Figure 2) will be calculated by using Equation 4.5:

$$\dot{Q}_{add} = \dot{m}_{wm} \cdot (h_3 - h_2) \tag{4.5}$$

Furthermore, Equation 4.5 will be used to calculate the turbine power by using enthalpies in States 3 and 4 rather than enthalpies in States 2 and 3 (see Figure 2). When calculating the turbine power, the isentropic efficiency of 80% has to be taken into account, *[4].*

A similar calculation is made for the condenser heat flow. The enthalpy difference used in Equation 4.5, is now the difference between States 4 and 5 (see Figure 2), *[7].*

The next step is the calculation of the water mass flow by taking into consideration the equality as in Equation 4.2; nevertheless, the water heat flow is now equal to the ORC system condenser heat flow. Equation 4.6 is used to calculate the water heat flow:

$$\dot{Q}_w = \dot{m}_w \cdot c_{p,w} \cdot \Delta T_w \tag{4.6}$$

Water mass flow may be calculated according to Equation 4.3 by taking the values and data for water.

The necessary pump power to raise the pressure from 2.5 to 20 bar is calculated according to Equation 4.5 by using, however, the enthalpy difference between States 1 and 5 (see Figure 2).

The COP number of the heat pump will be calculated using Equation 4.7.

$$COP = \frac{\dot{Q}_{HP}}{\dot{W}_{HP}} \tag{4.7}$$

Finally, the ORC system thermodynamic efficiency is calculated according to Equation 4.8:

$$\eta_{TD} = \frac{\dot{W}_t - \dot{W}_p}{\dot{Q}_{HP} + \dot{Q}_{add}} \tag{4.8}$$

Furthermore, the system contains a solar subsystem. Various parabolic trough solar collectors are used, more specifically the PTMx-36 model manufactured by Soltigua. The value of solar irradiation on a horizontal surface (G) in the area of the potential site is taken as the input data. The basis for the calculation using all the equations required to calculate the solar subsystem complies with *[9].*

The wood biomass system starts operating as soon as solar irradiation is insufficient for the operation of the solar subsystem. From the data and parameters, it is possible to calculate how much heat can be obtained annually from the solar subsystem, whereas the remaining amount of the total annual heat needed must be obtained from the wood biomass system. On the basis of the required amount of heat from wood biomass, we can calculate the quantity of wood chips needed per year for such a system; see Equation 4.9.

$$m_{wch} = \frac{Q_{WB}}{H \cdot \eta_b} \tag{4.9}$$

An economic analysis of the ORC process will also be carried out. In order to calculate certain economic indicators, the input data selected on the basis of experience, by the companies, according to the laws and guidelines in Slovenia, is needed.

The estimate of revenues and expenditure was made on the basis of initial investment costs, operating costs and maintenance costs, as well as potential revenues and the revenues arising from energy savings.

The initial investment costs were divided into funding investment, construction work, equipment with installation, and unforeseen work.

Funding investment is divided into costs for land and costs for documentation and engineering. The costs for land are assessed on the basis of previous experience, namely €5/m², whereas the costs for documentation and engineering work are assessed to 2% of the costs for solar collectors and 7% of the costs for the other equipment. The construction costs are divided into the costs of geological surveys, costs of well excavation, costs of soil preparation and costs of the facility and ancillary buildings. The costs of equipment and installations are mainly estimated on the basis of previous experience with certain data provided by manufacturers (Siemens, Hurst Boiler Inc., Soltigua). Regarding unforeseen work, the costs are assessed to 5% of the costs of equipment and installations.

The operating costs comprise all the data on the disbursements foreseen for the purchase of goods and services, which are not of an investment nature since they are consumed within each accounting period. The operating costs are divided into direct costs of production, administrative and general costs, as well as expenses arising from sales and distribution. The direct costs of production are divided into the costs of wood chips, estimated at €75/t (since a large quantity of wood chips is required, a 25% discount may also be taken into consideration), and the geothermal water consumption costs. Administrative and general expenses are estimated at 8% of staff costs. Costs of sales and distribution, however, are divided into staff costs, i.e. costs of salaries for four full-time employees and power distribution costs. Maintenance costs are estimated at 5% of investment costs.

The revenues are estimated according to the price of power generated from renewables, in particular from geothermal energy, for medium-sized units in Slovenia. The estimated useful life of a power plant taken into consideration was 25 years.

The revenues arising from energy saving are estimated in accordance with the price of CO_2 coupons, given that wood biomass may be regarded as CO_2 neutral. For the sake of comparison, lignite was taken instead of wood chips.

All the values described above are summarised in Table 3, *[7].*

Table 3: *Economic parameters*

Investment costs		
Category		Costs (€)
Funding investment	Land	525,990
	Documentation and engineering	632,572
Construction	Geological research	150,000
	Soil preparation	500,000
	Wellbore	1,300,000
	Building and supply buildings	100,000
Equipment with installation	Heat pump	2,081,230
	Pumps	199,925
	Heat exchangers	377,086
	Steam turbine	600,000
	Biomass boiler	1,203,218
	Solar collectors	11,726,000
	Pipelines and tubes	1,225,000
Unforeseen work		870,623
Operating and maintenance costs		
Category		Costs (€) per year
Direct production costs	Wood chips	1,032,304
	Geothermal water consumption	40,000
Administrative and general expenditures		7,520
Sales and distribution expenditures	Staff costs	94,000
	Distribution expenditures	350,000
Maintenance costs		1,074,582
Revenues and energy savings		
Category		€ per year
Energy savings		134,426
Category		Revenues (€)
Total revenues in 25 years of operation		26,503,716

5 RESULTS

The geothermal water inlet temperature is very low (40 °C), and it had to be preheated in a heat pump. The geothermal water heat flow that heated R134a in the heat pump amounts to 2,090 kW. As a result, the ORC system inlet heat flow amounts to 3,040 kW. This heat flow directly defines the mass flow of the ORC system working medium (R245fa), which is 55.27 kg/s. The desired turbine inlet temperature was 130 °C, which means that a large amount of additional heat flow has to be supplied to the system from the solar subsystem chosen as the first option. The quantity of additional heat flow is 10,501.3 kW. If the solar subsystem is not capable of producing such heat flow (depending on solar irradiation and weather conditions), R245fa as the working medium will be additionally heated in the wood biomass subsystem so as to finally reach 130 °C. The expansion of R245fa occurs in the turbine to a state of 2.5 bars and 73 °C in the range of overheated vapour (see Figure 2). Considering Figure 1, the working medium has to get to State 5 in which it enters the pump. It reaches State 5 by passing through the condenser in which it moves through a mixed area to the liquid phase. In the condenser, 12,048.9 kW of heat flow is removed from the water. The water used as a refrigerant must have its inlet temperature lower than the outlet temperature of the working medium in State 5. The water inlet temperature is 15 °C and outlet temperature 23 °C, which means that a relatively high water mass flow is required: 390.3 kg/s. The necessary power of the pump in the ORC system is 276.35 kW.

The total input heat flow is 13,541.3 kW, of which 22.45% from the heat pump and 77.55% is from additional sources. In the condenser, 12,048.9 kW of heat flow is released. Electrical power generated from the ORC system amounts to 1,768.64 kW, with 15.63% (276.35 kW) of it consumed by the pump and, therefore, the net recovered electrical power amounts to 1,492.3 kW. Another option is that the pump takes the power for its operation from the grid. Thermal efficiency is the ratio between the net generated power and the invested heat flow; it amounts to 11.02%. Figure 4 shows the power flows in the ORC system. The COP of a heat pump as the ratio of heat output to the amount of energy input of a heat pump amounts to 3.22.

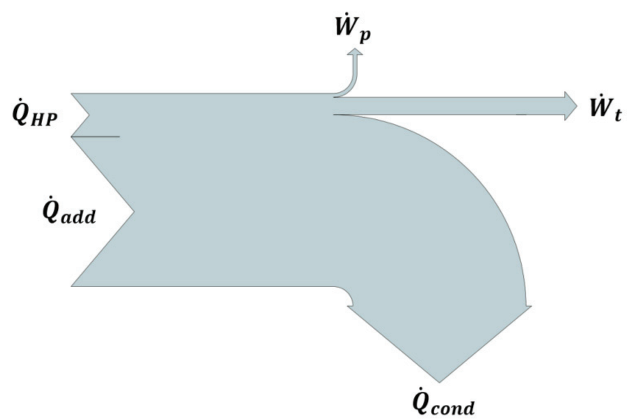

Figure 4: *ORC system power flow diagram*

To provide additional heating of the R245fa working medium in the ORC system, 10,501.3 kW of heat flow is needed. This is a rather large amount of heat and as a consequence, 286 units of PTMx-36 solar collectors are needed and approximately 5.5 hectares of land for their installation. The solar subsystem calculation was made on the basis of a fixed solar irradiation value. However, we know that the amount of solar irradiation changes throughout the day and, therefore, another subsystem is installed in the ORC system, i.e. the wood biomass system, which in our case requires quite a large quantity of wood chips per year. Since we know that we need approximately 10.5 MW of additional heat flow, we need 18,434 tons of wood chips per year for this purpose. The wood biomass system would operate mostly in winter and at night, when there are low levels of solar irradiation or none at all. All the above-described calculated values are indicated in Table 4.

Table 4: *Calculation results*

Parameter	Value	Parameter	Value
$\dot{m}_w$	390.3 kg/s	$\dot{Q}_{HP}$	3,040 kW
m_{wch}	18,434 t	Q_s	23,452 MWh
$\dot{m}_{wm}$	55.27 kg/s	Q_{WB}	50,141 MWh
N	286	S	55,198 m²
Q	73,593 MWh	$\dot{W}_p$	276.35 kW
$\dot{Q}_{add}$	10,501.3 kW	$\dot{W}_t$	1,768.64 kW
$\dot{Q}_{cond}$, $\dot{Q}_w$	12,048.9 kW	η_{TD}	0.1102
$\dot{Q}_{geo}$	2,090 kW	COP	3.22

The results of the economic analysis are not encouraging since the costs exceed the revenues. The investment was estimated at €21,491,644. The funding of the system with the estimated lifetime of 25 years would be provided through own sources. The cash flow plan was calculated on the basis of the estimated expenses and revenues (see Table 3). The ORC system has a negative cumulative cash flow, as shown in the diagram in Figure 5. Figure 5 shows a negative range throughout the diagram. By the 10th year of the operation, the slope of the graph is slightly less steep, because higher state subsidies for power production from renewables were taken into consideration. After the 10th year of the operation, however, the slope of the graph is even steeper, which means that a 100% return on investment cannot be expected due to the fact that the revenues are too low in relation to the current expenditure or in other words: the annual revenues fail to reach or exceed the annual revenues resulting in losses increasing one year after another.

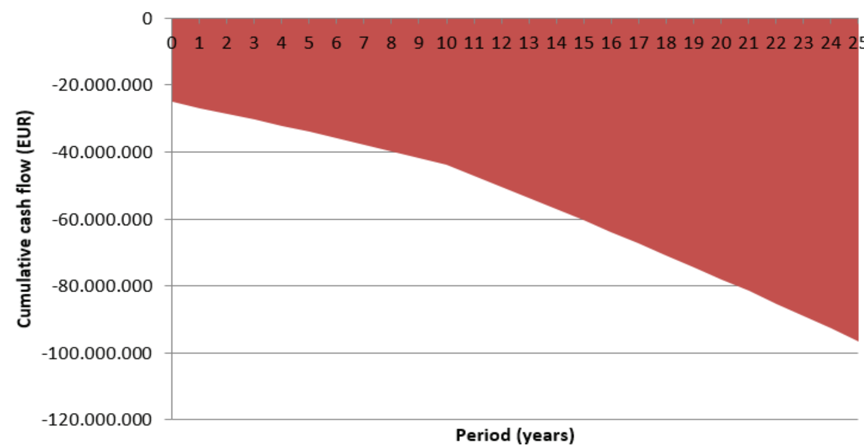

Figure 5: *Cumulative investment cash flow*

6 CONCLUSION

Currently, the use of RES is strongly encouraged. One of the options for their use is described in this paper: a system using three different renewable energy sources in combination with a heat pump. The temperature of the geothermal water from a wellbore, taken as the input data, is too low and had to be heated in a heat pump. The total input heat flow into the ORC process from the heat pump amounts to 22.45%, which is much more than if connecting the heat from geothermal water directly to the ORC process. However, we know that the temperature increases with the depth of the well, so it would probably make sense to choose a deeper well. The ORC system was modelled solely for electricity production and as a result, a considerable amount of additional heat flow had to be brought into the system from the solar subsystem and, consequently, many solar collectors are needed. If the desired amount of heat flow is not provided by the solar subsystem, a wood biomass subsystem is used to ensure the same required amount of additional heat flow. This system is not economically feasible. The ORC system with recuperation would be much more feasible, or geothermal water with such temperature would be used for heating and cooling systems. This paper presents an example of electrical energy production from a very low-enthalpy geothermal source in combination with other renewable energy sources and a heat pump. From an environmental aspect and, in view of the consequences of global warming, the use of these sources of energy will be crucial for electricity production in the near future.

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Nomenclature

(Symbols)	(Symbol meaning)
c_p	Specific heat capacity [kJ/kgK]
G	Solar irradiation [kWh/m^2]
h	Specific enthalpy [kJ/kg]
H	Heating value [kWh/kg]
$\dot{m}$	Mass flow [kg/s]
N	Number of collectors [-]
p	Pressure [bar], [Pa]
Q	Heat [kWh]
$\dot{Q}$	Heat flow [kW]
s	Specific entropy [kJ/kgK]
S	Surface area [m^2]
T	Temperature [°C], [K]
ΔT	Temperature difference [K]
V1, V2	Valves
$\dot{V}$	Volume flow [m^3/s]
$\dot{W}$	Power [kW]
η	Efficiency [-]
ρ	Density [kg/m^3]
(Subscripts)	(Subscript meaning)
add	Additional
b	Boiler
cond	Condenser
geo	Geothermal
HP	Heat pump
p	Pump
s	Solar
t	Turbine
TD	Thermodynamic

w	Water
WB	Wood biomass
wch	Wood chips
wm	Working medium
(Abbreviations)	(Abbreviation meaning)
COP	Coefficient of performance
ORC	Organic Rankine cycle
RES	Renewable energy source(s)

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HYDRAULIC TRANSIENT CONTROL OF REFURBISHED FRANCIS TURBINE HYDROPOWER SCHEMES IN SLOVENIA

BLAŽENJE PREHODNIH POJAVOV V SLOVENSKIH HIDROELEKTRARNAH Z OBNOVLJENIMI FRANCISOVIMI TURBINAMI

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Keywords: hydraulic transient regimes, Francis turbine, transient control strategies, computational model, field tests

Abstract

This paper presents hydraulic transient control methods of refurbished Francis turbine hydropower schemes in Slovenia. Transient control strategies are presented, including the alteration of operational manoeuvres, transient control devices, suitable water conveyance system layout and operational limits. Computational models and modern hydraulic transient control approaches are also outlined. The paper concludes with the practical implementation of two case studies: the refurbishment of Moste HPP and Doblar 1 HPP. Both hydropower plants are equipped with Francis turbine units and underwent refurbishment in 2010 to 2013, respectively.

Povzetek

Prispevek obravnava metode za blaženje negativnih posledic hidravličnih prehodnih pojavov v slovenskih hidroelektrarnah z obnovljenimi francisovimi turbinami. Negativne posledice prehodnih pojavov pojavov lahko blažimo s spremembo obratovalnih manevrov, vgradnjo varnostnih elemen-

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tov in ustreznim načrtovanjem pretočnega sistema hidroelektrarne. Predstavljen je moderni pristop k modeliranju in izbiri ustreznih metod. Praktični pristop je prikazan na dveh industrijskih primerih, HE Doblar 1 in HE Moste, ki imata kot pogonske agregate vgrajene francisove turbine in sta bili obnovljeni v letih 2010 do 2013.

1 INTRODUCTION

The refurbishment and upgrading of hydropower plants (HPP) are a growing concern in the hydro industry. The safety, efficiency, availability, and profitability of the plant should be investigated when considering the refurbishment and upgrading of it. The work may include the overhaul and/or replacement of components which are most affected by wear or the installation of new machinery. The increase of the output is normally achieved by improvement of the turbine efficiency and by increasing the turbine discharge. The increase of discharge and flexibility of load variation may result in much higher dynamic loads on both refurbished and non-refurbished plant components. The feasibility and design studies of a refurbished hydropower plant should include hydraulic transient analysis in order to ensure the safe and economic operation of the plant. Hydraulic transients are flow disturbances caused by a change from one steady state to another, [1]. Disturbances result in pressure changes induced by the propagation of pressure waves through the water conveyance system. The magnitude of the pressure changes associated with hydraulic transients can be large enough to cause serious damage to the system components, devices, and pipeline segments (e.g. pipe rupture). In addition, hydraulic transients can jeopardize the economic viability of the design, forcing the hydropower plant owner to spend a considerable amount of money in the form of prolonged and expensive repairs for leaks, breaks, poor system performance and increasing frequency of component damage, failure, and emergency maintenance, [2]. Awareness of the risks of hydraulic transients has led to significant progress in recent decades, especially after the introduction of the personal computer and special commercial software packages with continuing development and expansion into other technical fields, in which other types of transients (wind, electrical, open channel flow) are present. This has resulted in the consideration and inclusions of a transient analysis for most hydropower and other design projects. However, there is a strong need for further work on the development of a special guideline on hydraulic transients in hydropower plants that would bring together pieces from existing standards and guidelines, [3].

The first part of the paper is focused on transient operating regimes, hydraulic transient control strategies and a computational model used for numerical analysis. Particular attention is given to the role of the responsible engineer and modern hydraulic transient approaches. The second part of the paper presents a practical implementation of hydraulic transient analysis. Using commercial computer software, comparisons between computational and field measurements results are presented. Litostroj Power has more than 50 years of experience in the field of hydraulic transients for turbine and pump systems.

2 HYDRAULIC TRANSIENT OPERATING REGIMES

The main source of hydropower plant transients are operational manoeuvres of the turbine. During steady-state conditions, the load of the turbine equals the load of the generator. Any change of the current operational condition will result in the response of the turbine governor and, consequently, in the variation of the turbine rotational speed and pressure in the water conveyance system.

Transient loads are induced by a number of operating regimes. These may be classified as follows, [1], [3], [4]:

(1) *Normal transient operating regimes*
All hydraulic transient control devices in the system are assumed to be functioning as designed. These regimes include turbine start-up and load acceptance, load rejection under governor control and emergency shut-down.
(2) *Emergency operating regimes*
In this case, one of the control devices is malfunctioning leading to partial turbine runaway, closure of the turbine inlet valve (butterfly, spherical).
(3) *Catastrophic (exceptional) operating regimes*
Several control devices are malfunctioning in the most unfavourable manner; these may include full turbine runaway and closure of the surge tank butterfly valve under full discharge.

Additional operating regimes for transient analysis can be selected either by the hydropower plant owner or by the engineer responsible for the analysis:
(1) full load acceptance of the unit followed by full load rejection of the unit in the critical time interval to produce the maximum water level in the surge tank,
(2) full load rejection of the unit followed by full load acceptance of the unit in the critical time interval to produce the minimum water level in the surge tank,
(3) full load rejection with the wicket gates cushioning stroke inoperative,
(4) closure of the turbine inlet valve at set over-speed after full load rejection,
(5) rapid closure of the wicked gates (reaction turbine) or nozzle (action turbine) in less than the wave reflection time $T = 2L/a$ (L = conduit length; a = wave speed).

In pump-turbine plants, hydraulic transients in pumping mode of operation should also be investigated. Apart from this, the pump-turbine (turbine) unit might operate in synchronous compensation mode. Water column separation (transient cavitation) and resonance should be avoided in hydropower schemes whenever possible.

3 HYDRAULIC TRANSIENT CONTROL

Hydraulic transient loads can be kept within the prescribed limits (e.g., pressure in the flow-passage system, turbine rotational speed, surge tank water level, etc.) with the methods that fulfil the following criteria [5]:
(1) ensure the safety of the plant and personnel during any hydraulic transient regimes,
(2) identify the most severe adverse conditions and take adequate measures to ensure that hydraulic transient parameters remain within the design values,
(3) establish reasonable design limits for specific operational parameters.

The installation of a transient control device itself does not guarantee safety and can introduce additional risk into the system. If the control device is not fault-tolerant, redundancy is required, accompanied by increased inspections and maintenance costs, [2]. Operational, safety, and economic factors are therefore decisive for the selection of protection against undesirable hydraulic transient effects. The best solution may be a combination of different design approaches, [3], [4].

(1) Alteration of operational regimes. This includes appropriate control of the wicket gate manoeuvres and shutoff valve closing/opening times. A two-speed wicket gate closing time function with an added cushioning stroke is recommended. Alteration of the operating regime is the most efficient method for hydraulic transient control in cases of refurbished hydropower plants due to the low cost of the work involved.

(2) Installation of surge control devices in the system. The protective devices are installed on the water conveyance system as system components in order to alter the overall system characteristics (shorten the active conduit length, reduce the effects of liquid compressibility, increase the turbine inertia).

The protective devices may include:
(i) increased turbine unit inertia (adding flywheels to small units, increasing the generator inertia),
(ii) resistors (to absorb excessive power),
(iii) surge tank in headrace and/or tailrace (shortens the active conduit length, improves governing stability) or air cushion surge chamber (more complicated, requires compressed air supply),
(iv) pressure-regulating valve (operates synchronously with the turbine guide vane mechanism),
(v) pressure-relief valve (opens at a set pressure, small units),
(vi) rupture disc (bursts at a set pressure, small units),
(vii) aeration pipe (attenuates water column separation effects) or air valve (attenuates water column separation effects, reduces negative axial hydraulic thrust); both release unwanted air from the pipeline.

(3) Redesign of the water conveyance system layout. Redesign together with corresponding operational regimes is the most efficient method for hydraulic transient control in the case of new hydropower plant developments while there are severe cost constraints for the redesign of the water conveyance system layout in case of refurbished hydropower plants (civil works). It should be noted that the rehabilitation process offers the advantage of allowing comparative hydraulic transient tests in the plant before and after rehabilitation. In contrast, the design of a new plant is based on industry guidelines and good engineering practice.

4 HYDRAULIC TRANSIENT ANALYSIS

Hydraulic transient analysis is traditionally undertaken with deterministic models, [1], that treat a number of transient regimes based on experience, guidelines, and codes. In addition, parametric analysis accounts for uncertain parameters (e.g., skin friction, wave speed, entrained air). The tasks and responsibilities of the hydraulic engineer are to identify and treat transient regimes that may cause operational problems or endanger the safe operation of the hydropower plant and its personnel and to provide solutions for a safer and more economical operation. From the aforementioned scope of possibilities regarding hydraulic transient operation and prevention (Sections 2 and 3), it is clear that the engineer must have a broad interdisciplinary range of knowledge in different fields of engineering. The extent of analysis will depend on the particular owner specifications, type of machine, the complexity of the water conveyance system and design phase. The plant owner can specify transient regimes for

analysis according to a planned sequence of operation of the hydropower plant. The type of machine will govern the use characteristics and also influence the complexity of the water conveyance system. Hydraulic transient analysis can be, at an early stage of the design process (preliminary, conceptual design), performed with simplified models that treat hydraulic transient regimes based on experience, guidelines, and codes, [1], [3], [6]. In the early stage of design, appropriate methods for limiting transient loads can be selected, especially the change of the conduit profile, the dimensions and the positions of the system components. In the later stage of the design process, numerical methods, [1], [7], are applied, the detailed transient regimes are identified, and the surge control devices are selected. The analysis should include cases with extreme values of discharge and heads when either one unit or all units operate, cases with malfunctions of one of the devices and cases with unfavourable sets of events. These results form the basis for risk analysis to transients in hydropower plants, [8]. During the commissioning of the hydropower plant, the engineer should assist the commissioning team in the field with additional analysis in cases in which the on-site boundary conditions differentiate from those assumed in the detailed design.

There are a number of commercial software packages available and adequately verified by vendors and end users. The same applies to in-house software codes. The hydraulic transient analysis in this paper is performed using the SIMSEN commercial computer software package, [9]. This software is based on a modular structure and composed of objects, each representing a specific element in the network. Each element includes a set of differential equations based on the network element model. Hydraulic elements are modelled as RLC electrical circuits according to the impedance method, [10], in which the unknown quantities are (1) piezometric head h at the node and (2) the discharge Q through each component, corresponding to the voltage U and current i, respectively. The following mass conservation and momentum equations provide the basis for an equivalent electrical circuit modelling; see Figure 1, [11],

$$\frac{\partial h}{\partial t}+\frac{a^2}{gA}\frac{\partial Q}{\partial x}=0, \tag{4.1}$$

$$\frac{\partial h}{\partial x}+\frac{1}{gA}\frac{\partial Q}{\partial t}+\frac{f\,Q\,|\,Q\,|}{2gDA^2}=0. \tag{4.2}$$

Note that all symbols are defined in the Nomenclature. A quasi-steady approach for estimating skin friction losses in the pipeline is adopted for slow transients. Equations (4.1) and (4.2) are solved by using the finite difference method [11]. This approach leads to a system of ordinary differential equations that can be represented as a T-shaped equivalent scheme as depicted in Figure 1. The RLC parameters of this equivalent scheme defined for a length *dx* are, [11],

$$R=\frac{f|Q|}{2gDA^2}\,dx,\quad L=\frac{1}{gA}dx,\quad C=\frac{gA}{a^2}dx. \qquad (4.2)$$

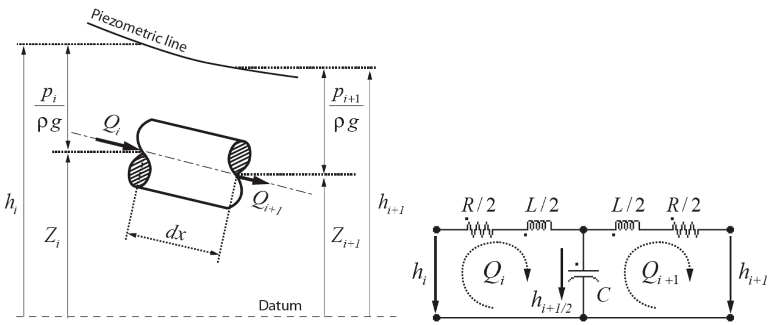

Figure 1: Modelling of a pipe of length *dx* (left) and a corresponding equivalent scheme, [10]

Boundary conditions (valve, surge tank, Francis turbine, etc.) are also defined as RLC elements. For example, the Francis turbine boundary condition represented as a set of RLC elements is depicted in Figure 2. Assuming that the transition between two operating points of a turbine corresponds to a succession of steady-state points, the transient behaviour of a hydraulic machine can be modelled using the steady-state characteristics (hill chart). Turbine characteristics given in the form of unit speed (n_{11}), unit discharge (Q_{11}) and unit torque (M_{11}) are used in SIMSEN. RLC models of pipes and of boundary conditions are set-up using Kirchoff's laws. The time domain integration of the full hydropower system is carried out with a Runge-Kutta fourth-order procedure, [11].

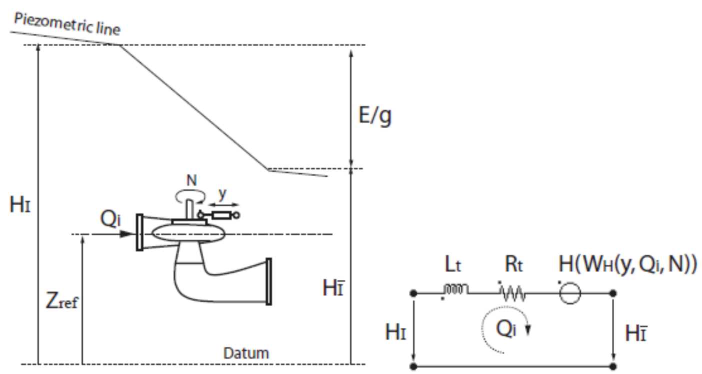

Figure 2: Francis turbine model (left) and a corresponding equivalent scheme [10]

5 TRANSIENTS IN THE DOBLAR 1 HYDROPOWER PLANT

The Doblar 1 HPP is a storage/run-of-river hydropower plant on the Soča river in Slovenia and has been in continuous operation since 1939. The original turbine equipment (3 units) was manufactured by Riva Milano and until 1947 produced electrical energy for the Italian grid with a grid frequency of 42 Hz. In 1950, the plant changed ownership and, together with the rest of

the Slovenian grid, changed to a grid frequency of 50 Hz. Unit 1 was refurbished in 2001 with a turbine manufactured by Litostroj, and all three units were refurbished and upgraded from 2010 to 2013.

The water conveyance system is a complex combination of the following elements: headrace tunnel with a length of 3735 m and 5.6 m diameter, surge tank system including two ellipse-shaped orifice surge tanks (combined cross section area 880 m² with 12 orifices) and cylindrical surge shaft, three parallel penstocks with a length of 46 m and 3.0 m diameter, three 9.5 MW vertical shaft Francis turbine units of rated head H_r = 46.0 m and rated discharge Q_r = 25.0 m³/s each connected to its own downstream surge tank and tailrace tunnel, and downstream reservoir; see Figures 3 and 4. The rated speed of the turbine is n_r = 300 min^{-1} and the polar inertia of the unit rotating parts is I = 84.70×10³ kgm². Each turbine is equipped with a spherical turbine inlet valve with a diameter of D_v = 2.3 m. Due to the age of the hydropower plant and the historical context of the hydropower plant location (change of the country ownership after the Second World War) limited drawings of the upstream and downstream surge tank system were available. Careful on-site surveying established a more detailed picture for the hydraulic transient modelling calibration.

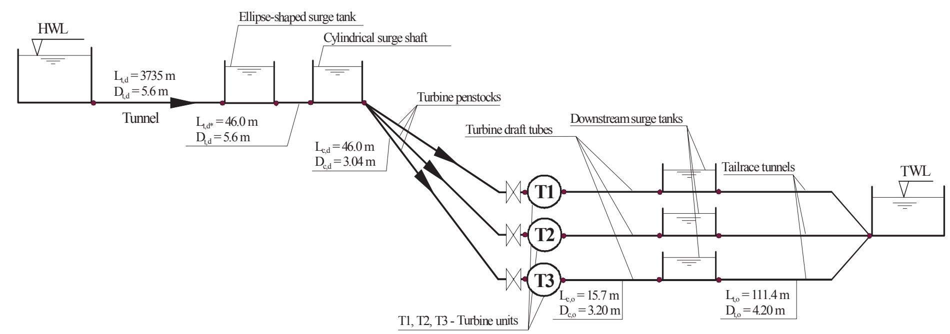

Figure 3: *Layout of Doblar 1 HPP, Slovenia*

The results for the simultaneous sudden full-load rejection of the three turbine units [12], [13], are presented, including guide wicket gates position (y), turbine rotational speed (n), and turbine inlet (H_{ti}) and draft tube pressure heads (H_{dt}); see Figure 5. The units are operating at generator output $P_{gen,1}$ = 11.0 MW, $P_{gen,2}$ = 11.0 MW, $P_{gen,1}$ = 11.0 MW and headwater level HWL = 152.4 m.a.s.l. The turbines are disconnected from the electrical grid after a period of steady-state operation. The electromagnetic torque of the generator drops to zero instantaneously; as a result, the turbine rotational speed of each unit increases. The closure of the wicket gates with the prescribed two-speed closing law to speed no-load reduces the hydraulic torque and consequently limits the maximum turbine rotational speed and pressure oscillations in the flow passage system.

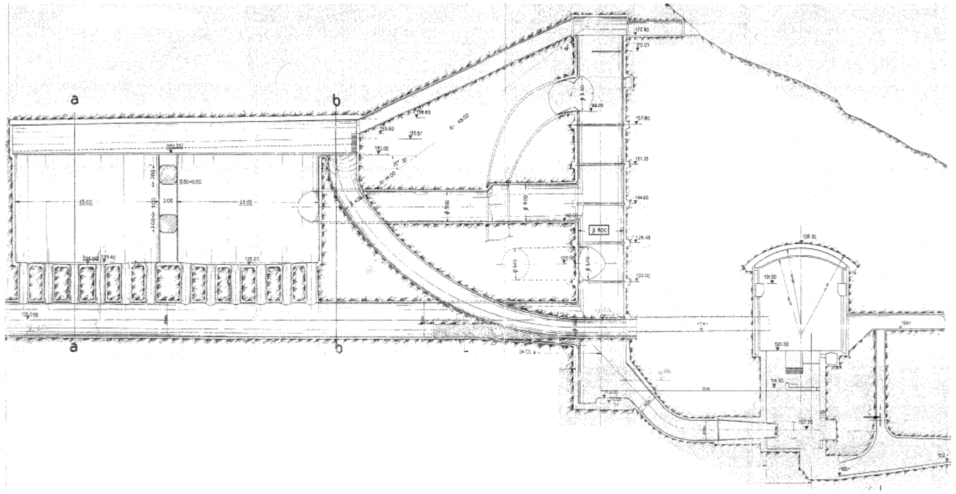

Figure 4: *Layout of the upstream end surge tank system in Doblar 1 HPP, Slovenia*

Results are validated for Unit 3. As seen from Figure 5, the maximum calculated turbine inlet pressure head $H_{ti,max,c}$ = 44.2 m is higher than the measured one $H_{ti,max,m}$ = 43.0 m. A good comparison can be observed during the wicket gate closing sequence, while the measured values of the turbine inlet pressure oscillate at a higher level due to the cylindrical surge shaft influence (inflow from the ellipse-shaped surge tanks). The maximum calculated turbine speed $n_{max,c}$ = 405.5 min^{-1} is higher than the measured one $n_{max,m}$ = 391.5 min^{-1} and the calculated maximum draft tube pressure head $H_{dt,max,c}$ = 3.9 m is also higher than the measured head $H_{dt,max,m}$ = 1.8 m (average of peak values). During the wicket gates closing sequence and speed no-load operation, high-frequency pulsations are present at draft tube pressure measurements (noise).

Figure 6 shows a comparison between the calculated and the measured water level oscillations in the cylindrical surge shaft (Z_{ss}) and the turbine inlet pressure for a longer time interval. During the wicket gate closing sequence, the ellipse-shaped surge tanks have no influence on the turbine inlet pressure but contribute to the cylindrical surge shaft oscillations with an additional discharge through the connecting tunnel between the surge tanks and the surge shaft. The overall discrepancies between the computed and the measured results might be contributed to a simplified modelling of a complex surge tank system and uncertain data on the inlet-outlet losses for both surge tanks.

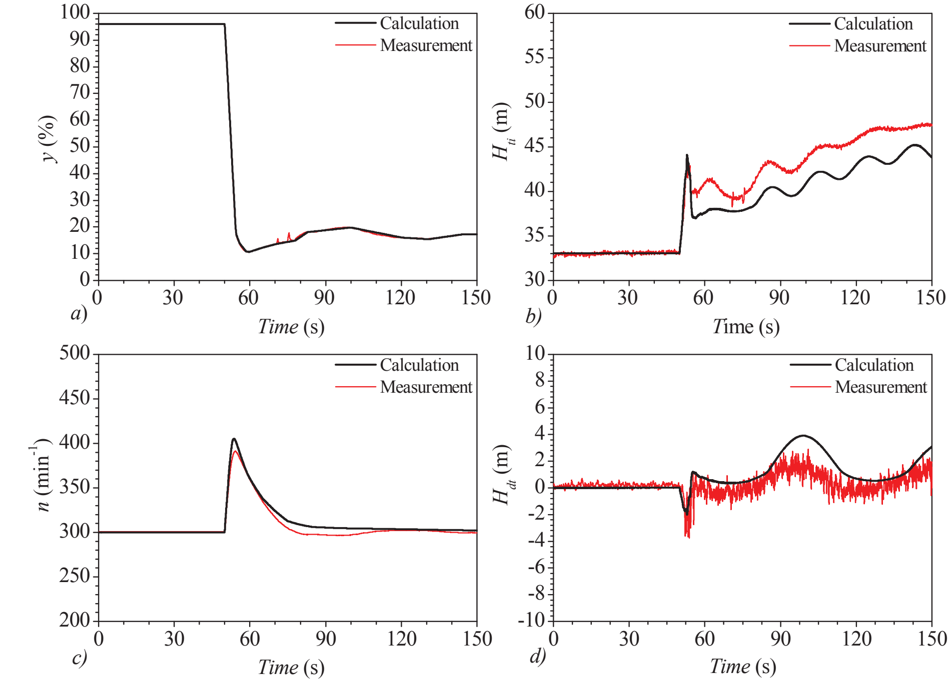

Figure 5: *Comparison of computed and measured results after simultaneous sudden load rejection of the three units; Doblar 1, Slovenia*

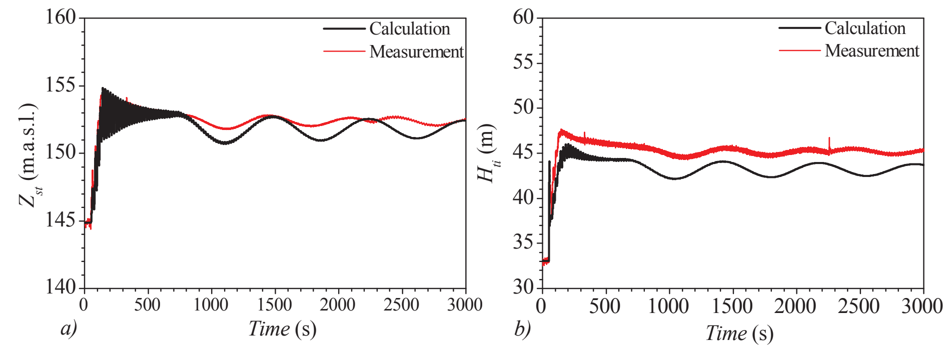

Figure 6: *Water level oscillations in upstream cylindrical surge shaft and pressure for Unit 3 for the case of simultaneous sudden load rejection of the three units; Doblar 1, Slovenia*

6 TRANSIENTS IN THE MOSTE HYDROPOWER PLANT

The Moste HPP was the first hydropower plant on the Sava River, Slovenia, in 1952. The concrete arch-gravity dam lies in the narrowest portion of the Sava Canyon, in the Kavčke gorge below Žirovnica, which with its 60 m height is also the highest dam in Slovenia. The storage reservoir enables a weekly management of the flows. Moste HPP was designed as a storage power plant for the production of peak energy. The original configuration of Moste HPP together with Unit 4, which exploits the hydro potential of the Završnica Creek (Završnica River water conveyance system), represents a complete energy system; see Figure 7. The Završnica HPP was built in 1914 as one of the first large hydropower plants in Slovenia. It was equipped with two horizontal-shaft 1.1 MW Pleton turbines with additional flywheels, both manufactured by Tönnis Ljubljana. In 2005, after 90 years of operation, production stopped, and HPP Završnica became a technical museum. In the first stage, three vertical shaft Francis turbine units were installed in the Moste HPP powerhouse with the total discharge capacity of 28.5 m³/s. The system was supplemented in 1977 with the installation of a fourth Francis type pump-turbine unit. The system was designed so as to allow the pumping of the water from the Sava River into the Završnica storage reservoir during surplus energy production which, unfortunately, due to the pollution of the Sava River, ceased to operate. Because of this, Unit 4 was reconstructed to operate in turbine operational mode only. Due to the severe landslide problems and need for modernization, it was decided to replace the three units with two larger units. The space of Unit 2 was abandoned and used for the construction of a reinforced powerhouse so as to decrease the unfavourable effects of the powerhouse structure deformation.

Transient events in the Sava River water conveyance system are presented in this paper. The system is comprised of an upstream reservoir, a headrace tunnel with a length of 840 m and a diameter of 3.0 m, a surge tank with lower and upper side galleries, a penstock with a length of 152.5 m and a diameter of 2.6 m, two vertical-shaft 7.5 MW Francis units of rated head H_r = 58.07 m and discharge Q_r = 13.0 m³/s which are connected to a common tailrace tunnel, measuring 1500 m in length and 4.0 m in diameter, and a downstream reservoir.

The headwater level (*HWL)* is in the range from 510.0 m.a.s.l. to 524.75 m.a.s.l.; the tailwater level (*TWL*) is in the range from 454.28 m.a.s.l. to 457.90 m.a.s.l. The rated speed of the turbine is n_r = 500.0 min^{-1} and the polar inertia of the unit rotating parts is $I = 20.25\times10^3$ kgm². Each of the turbines is equipped with a butterfly turbine inlet valve with a diameter D_v = 1.6 m. The turbine inlet valve and the spiral casing centrelines are at the same level of 457.53 m.a.s.l.

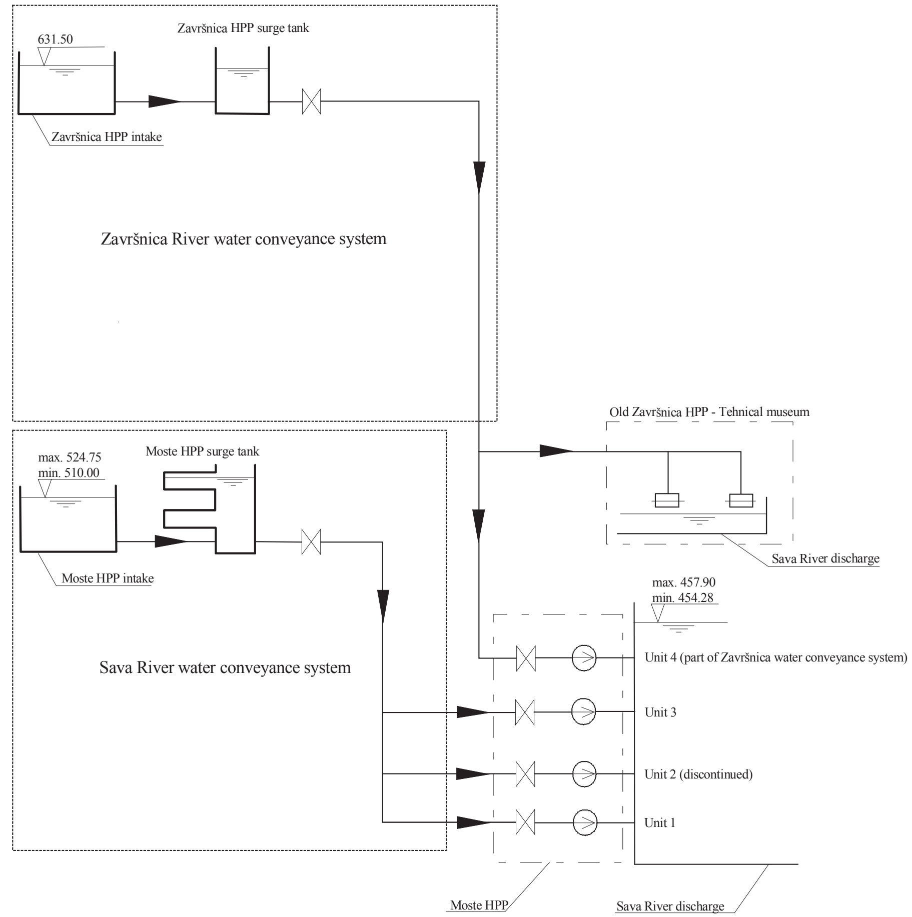

Figure 7: *Sava and Završnica Rivers water conveyance systems*

Various operating regimes were performed during the commissioning tests of new units, including turbine start-up, load acceptance, sudden load rejection, emergency shutdown and closure of one or two turbine inlet valves under various flow conditions. The resulting water hammer was controlled by the appropriate adjustment of wicket gates and turbine inlet valve closing manoeuvres. The computed and the measured results from the sudden simultaneous full-load of two turbines are compared, [13], [14]. The units are operating at a generator output $P_{gen,1} = P_{gen,2}$ = 6.7 MW and headwater level at *HWL*= 524.75 m.a.s.l. The pressure head at the turbine inlet H_{ti}, the turbine rotational speed n and wicket gates position y are shown in Figure 8. The calculated maximum head $H_{ti,max,c}$ = 87.3 m is higher than the measured one $H_{ti,max,m}$ = 81.5 m. As can be seen from the results, the maximum computed turbine inlet pressure head exhibits a peak value during the wicket gate cushioning stroke; there is no such peak at measured results. There is good agreement between the results of computations and measurements in the initial phase of the wicket gate closing event. The calculated maximum turbine rotational speed $n_{max,c}$ = 711.5 min^{-1} is higher than the measured turbine rotational speed $n_{max,m}$ = 696.2 min^{-1}.

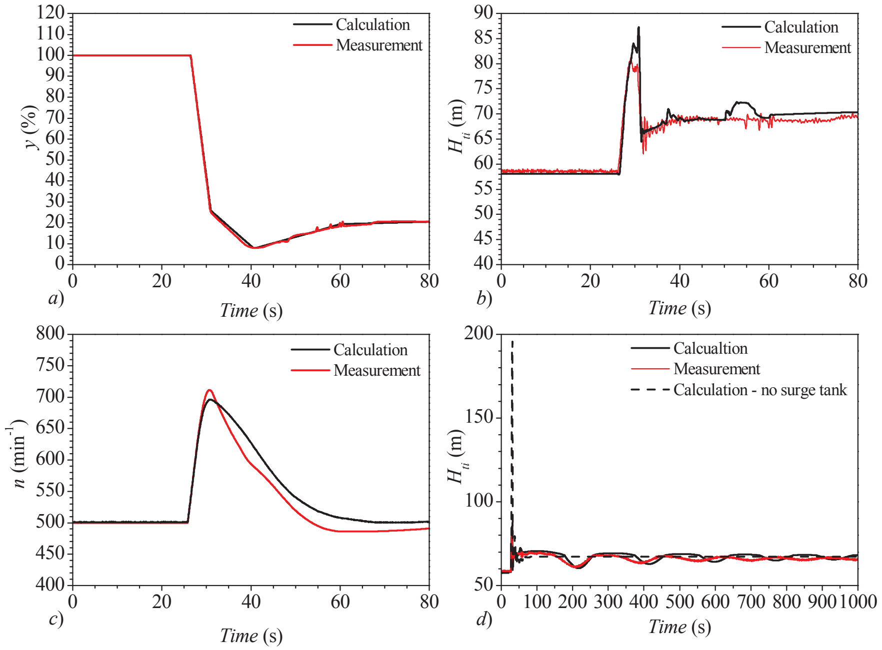

Figure 8: *Comparison of computed and measured results after simultaneous sudden load rejection of the two units; Moste HPP, Slovenia*

Figure 8d shows turbine inlet pressure head oscillations over a longer period. The beneficial effects of the surge tank on water hammer loads during sudden full-load rejection can be observe: the computed maximum head $H_{ti,max,c}$ = 87.3 m of the system with a surge tank is much lower than the computed maximum head $H_{ti,max,c}$ = 194 m of the system without the surge tank.

7 CONCLUSIONS

This paper presents an overview of the hydraulic transient analysis of refurbished Francis turbine hydropower schemes with complex water conveyance systems in Slovenia. The undesirable transient effects may disturb the overall operation of the plant and damage the system components. The introduction of the personal computer and, as a consequence, the development of special commercial software packages has increased awareness towards the importance of hydraulic transient analysis. Nevertheless, the engineer must have a broad interdisciplinary range of technical knowledge. Operating regimes for analysis and subsequent transient control must be selected according to the characteristics of the power plant scheme bearing in mind safety, reliability, and costs. Complete documentation of the water conveyance system is especially important in cases of refurbishment. Two case studies of refurbishment have been presented; the Doblar I hydropower plant on the Soča River and the Moste hydropower plant on the Sava River. In both cases, the hydraulic transient control devices are turbine governors coupled to the wicket gates servomotor with a two-stage stroke and surge tank(s). RLC equivalent scheme modelling computational results agree well with the results of the measurements.

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Nomenclature

(Symbols)	(Symbol meaning)
A	pipe area
a	water hammer wave speed
C	capacitance

dx	distance along the pipe
D	pipe diameter, diameter
f	Darcy-Weisbach friction factor
g	gravitational acceleration
H	pressure head, head
h	piezometric head
I	polar inertia
L	conduit length, inductance (equation 4.2)
M	torque
n	rotational speed
P	output power
p	pressure
Q	discharge
R	resistance
T	wave reflection time
t	time
W_H	Suter head characteristic (Figure 2)
Z	water level
ρ	density
(Subscripts)	(Subscripts meaning)
c	calculated
dt	draft tube
gen	generator
in	inflow
m	measured
max	maximum
out	outflow
r	rated value
ss	surge shaft
ti	turbine inlet
v	valve
0	initial conditions
11	unit value
1,2..	number of the unit
(Superscripts)	(Superscripts meaning)
(Abbreviations)	(Abbreviations meaning)

HWL	Headwater level
RLC	Resistance-inductance-capacitance
TWL	Tailwater level

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THREE-PHASE FUZZY MODEL OF A DYNAMIC PRODUCTION SYSTEM

TRIFAZNI MEHKI MODEL DINAMIČNEGA PROIZVODNEGA SISTEMA

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Keywords: dynamic production system, control, fuzzy model, fuzzy reasoning.

Abstract

In this article, a three-phase fuzzy model of controlling a dynamic production system is presented. A power supply system can be an example of such a system. Fuzzy system control follows a stochastic mathematical closed-loop model of the control of stocks (additional capacities) in a production system. The fuzzy model is demonstrated with a numerical example.

Povzetek

V članku je predstavljen trifazni mehki model v procesu upravljanja dinamičnega proizvodnega sistema. Takšen sistem je lahko tudi energetski sistem. Mehko upravljanje sistema izhaja iz slučajnostnega matematičnega zaprtozančnega modela upravljanja zalog v proizvodnem sistemu. Mehki pristop vpeljemo z uporabo trifaznega sistema mehkega sklepanja in pomeni približek zaprtozančnemu sistemu upravljanja. Mehki algoritem je ilustriran z numeričnim primerom.

1 INTRODUCTION

Every production system is a complex dynamic system. If a theoretical mathematical dynamic model of it is to be created, a great many variables and their interrelationships have to be taken into

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consideration. However, with methods of logical and methodological decomposition, every may be divided into a finite set of simpler subsystems, which are then studied and analysed separately, [1]. A model of optimal control is determined with a system, its input/output variables, and the optimality criterion function. The system represents a regulation circle, which generally consists of a regulator, a control process, a feedback loop, and input and output information. In this article, dynamic production systems will be studied. The optimality criterion is the optimal and synchronized balancing of planned and actual output functions, [2].

Let us consider a production model in a linear stationary dynamic system in which the input variables indicate the demand for products manufactured by a company. These variables can be deterministic, stochastic or fuzzy.

The fuzzy approach to the control of dynamic systems is approximately 50 years old. Thierry et al., [3] described the development of the fuzzy system control. From 1965 to 1985, the heuristic approach was pioneered, and earlier industrial applications were made. From 1985 to 2005, the model base approach was developed, including fuzzy modelling, model base fuzzy control design and adaptive fuzzy control. Since 2005, there have been new improvements in TS (Tagaki-Sugeno) system analysis, such as non-quadratic Lyapunov functions, delay, fuzzy-polynomial techniques, shape-dependent laws, asymptotic exactness, and adaptive control.

In this article, a new fuzzy approach to the control of dynamic systems is presented. It is based on the fuzzy inference rules in the if-then form. In Usenik, [4], the two-phase system was defined, and in this article a new and innovative expansion is developed.

2 DEFINING THE PROBLEM

Demand for a product should be met, if possible, by the current production. The difference between the current production and demand is the input function for the control process; the output function is the current stock/additional capacities, [4]. When the difference is positive, the surplus will be stocked, and when it is negative, the demand will also be covered by stock. In the case of a power supplier, stock in the usual sense does not exist (such as cars or computers, etc.); energy cannot be produced in advance for a known customer. The demand for energy services is neither uniform in time nor known in advance. It varies, has its ups (maxima) and downs (minima), and can only be met by installing and activating additional proper technological capacities, [5]. Because of this, the function of stock in the energy supply process is held by all the additional technological potential/capacities large enough to meet periods of extra demand.

The output function measures the amount of unsatisfied customers or unsatisfied demand in general. When this difference is positive, i.e. when the power supply capacity exceeds the demand, a surplus of energy will be made.

For this model, the regulation circuit is given in Figure 1, [4]. The task is to determine the optimum production and stock/capacities so that the total cost will be as low as possible, [1].

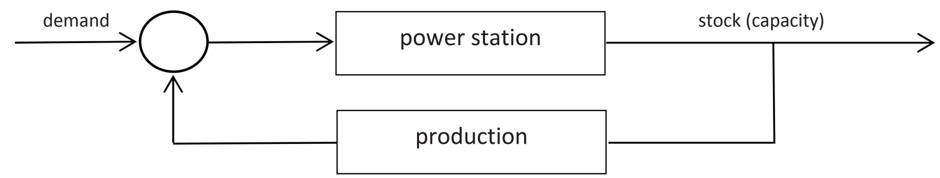

Figure1: *Regulation circuit of the production system*

3 FUZZY MODEL

Construction of a fuzzy system takes several steps, [6], [7]: selection of decision variables and their fuzzification, establishing the goal and the construction of the algorithm (base of rules of fuzzy reasoning), inference and defuzzification of the results of fuzzy inferences. A graphic presentation of a fuzzy system is given in Figure 2, [8].

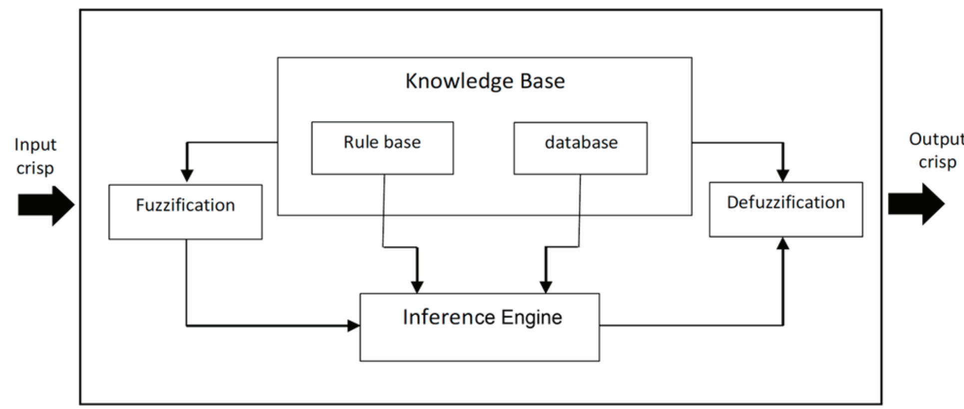

Figure 2*: Architecture of a fuzzy expert system*

In, [4], a fuzzy two-phase system, given in Figure 3, was designed.

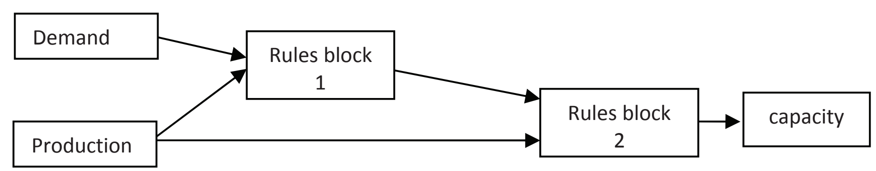

Figure 3*: The fuzzy two-phased system*

Now, this fuzzy model will be expanded, and a three-phase fuzzy model will be created.

Following the dynamic system, there are two subsystems in the first phase: system DEMAND and system PRODUCTION.

Let us assume that the demand (Figure 4) depends on:

- the market area,
- the density of the area,
- the price,
- the season,
- the uncertainty

and the production (Figure 5) on:

- the costs of production,
- the policy,
- the season,
- the weather, and
- the uncertainty.

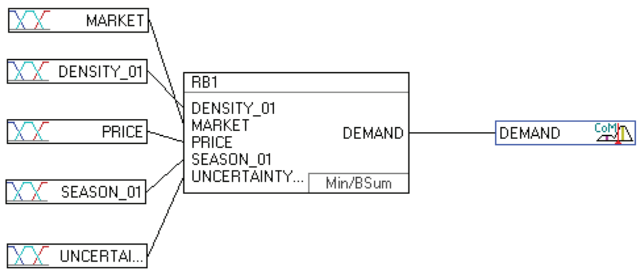

Figure 4*: The fuzzy subsystem "demand"*

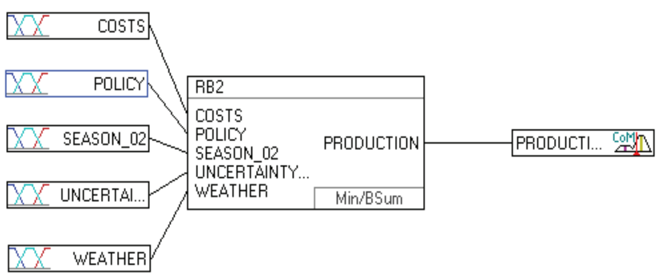

Figure 5*: The fuzzy subsystem "production"*

In the second phase, the output "SUPPLY" depends on the fuzzy input variables "demand" and "production"; in the third phase, with the output "CAPACITY" we have the fuzzy input variables "supply" and "production" (Figure 6).

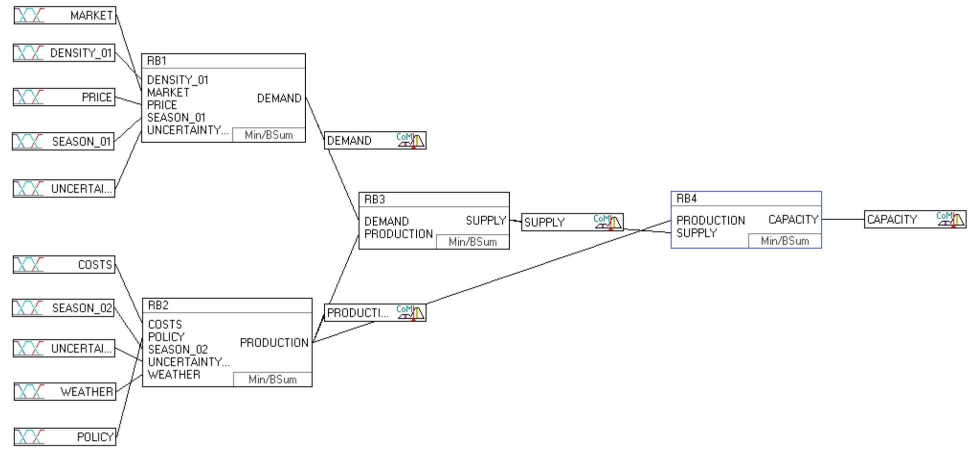

Figure 6*: The fuzzy three- phase system*

We assume that all expressions in our model are fuzzy variables.

3.1 Fuzzification

In the fuzzification procedures, fuzzy sets for all fuzzy variables (input and output) must be defined, as well as their membership functions. Every fuzzy variable is presented by more terms/fuzzy sets. In our system, there are fourteen fuzzy variables: the market area, the density of the area (density_01), the price, the season_01, the uncertainty_01, the demand, the costs of production, the policy, the season_02, the weather, the uncertainty_02 and production in the first phase and capacity_01 in the second phase and, finally, in the third phase the capacity as output of the system.
Fuzzy sets are given by terms below.

In the first rules block (subsystem_01):

- the input fuzzy variable MARKET AREA is represented by the fuzzy sets: SMALL, BIG,
- the input fuzzy variable DENSITY OF THE AREA (DEeNSITY_01) is represented by the fuzzy sets: WEAK, MEDIUM, STRONG,
- the input fuzzy variable PRICE is represented by the fuzzy sets: LOW, MEDIUM, HIGH,
- the input fuzzy variable SEASON_01 is represented by the fuzzy sets: LOW, HIGH,
- the input fuzzy variable UNCERTAINTY_01 is represented by the fuzzy sets: SMALL, MEDIUM, BIG, VERY_BIG,
- the output fuzzy variable DEMAND is represented by the fuzzy sets: VERY_LOW, LOW, MEDIUM, HIGH, VERY_HIGH.

In the second rule block (subsystem_02):

- the input fuzzy variable COSTS is represented by the fuzzy sets: LOW, NORMAL, HIGH,
- the input fuzzy variable SEASON_02 is represented by the fuzzy sets: LOW, HIGH,
- the input fuzzy variable UNCERTAINTY_02 is represented by the fuzzy sets: SMALL, MEDIUM, BIG, VERY_BIG,
- the input fuzzy variable WEATHER is represented by the fuzzy sets: GOOD, BAD,
- the input fuzzy variable POLICY is represented by the fuzzy sets: BAD, MEDIUM, GOOD,
- the output fuzzy variable PRODUCTION is represented by the fuzzy sets: LOW, MEDIUM, HIGH.

In the third rule block (second phase):

- the input fuzzy variable DEMAND is represented by the fuzzy sets: VERY_LOW, LOW, MEDIUM, HIGH, VERY_HIGH,
- the input fuzzy variable PRODUCTION is represented by the fuzzy sets: LOW, MEDIUM, HIGH,
- the output fuzzy variable SUPPLY is represented by the fuzzy sets: VERY_LOW, LOW, MEDIUM, HIGH, VERY_HIGH.

In the fourth rule block (third phase):

- the input fuzzy variable SUPPLY is represented by the fuzzy sets: VERY_LOW, LOW, MEDIUM, HIGH, VERY_HIGH,
- the input fuzzy variable PRODUCTION is represented by the fuzzy sets: LOW, MEDIUM, HIGH,
- the output fuzzy variable CAPACITY is represented by the fuzzy sets: VERY_LOW, LOW, MEDIUM, HIGH, EXTREMELY_HIGH.

For every fuzzy set, membership functions must be created (Figures 7-18). On the x-axis, the measures would be given in units, such as the number of customers, EUR, EUR/kWh, MWh, and so on, depending on the data. On the y-axis, membership in the interval [0, 1] is measured for every possible fuzzy variable and for every fuzzy set.

Due to the uniqueness of this model, we suppose that all units for all fuzzy variables are given in relative measure, i.e. percentages from 0 to 100. Of course, the expert knows what, for example, 30% for "weather" or 80 % of the "price" etc. means.

The fuzzy variables SUPPLY and CAPACITY are outputs of the fuzzy system.

SUPPLY means a quantity of the goods, which is delivered to the customers on the basis of the demand directly from the factory by the current production.

The fuzzy variable CAPACITY means extra capacities that should be added in the process of the production if it is not sufficient for current demand.

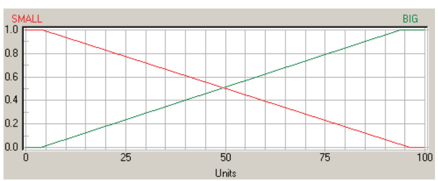

***Figure 7**: MBF of "MARKET"*

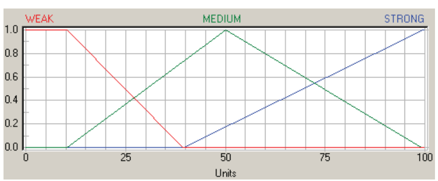

***Figure 8**: MBF of "DENSITY_01"*

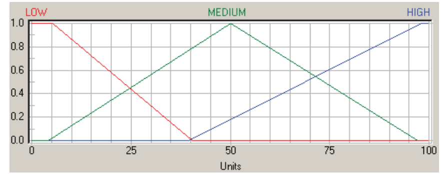

***Figure 9**: MBF of "PRICE"*

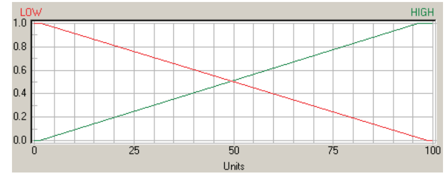

***Figure 10**: MBF of "SEASON"*

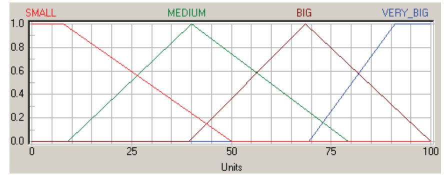

***Figure 11**: MBF of "UNCERTAINTY"*

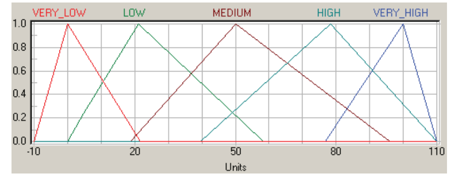

***Figure 12**: MBF of "DEMAND"*

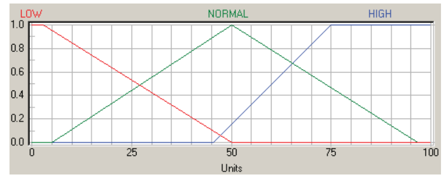

***Figure 13**: MBF of "COSTS"*

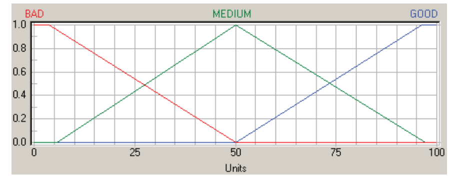

***Figure 14**: MBF of "POLICY"*

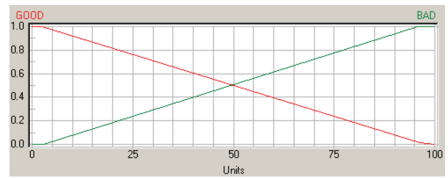

***Figure 15**: MBF of "WEATHER"*

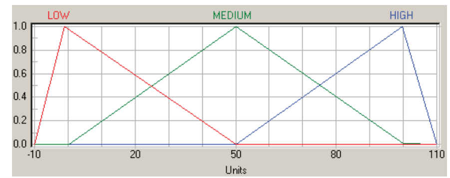

***Figure 16**: MBF of "PRODUCTION"*

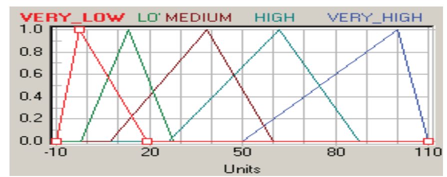

***Figure 17**: MBF of "SUPPLY"*

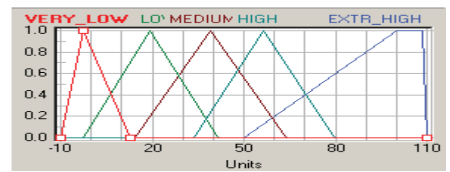

***Figure 18**: MBF of "CAPACITY"*

3.2 Fuzzy inference

Fuzzy inference is a process in which a certain conclusion is derived from a set of fuzzy statements. In addition to linguistic variables, there are basic widgets of a fuzzy logic system as well as sets of rules that define the behaviour of a system. A single fuzzy rule (implication) assumes the form: *if x is A, then y is B,* where *A* and *B* are linguistic values defined by fuzzy sets on the universes of discourse *X* and *Y,* respectively. Variables *x* and *y* are defined by the sets *X* and *Y*. With fuzzy inference, we must put all values and facts in a definite order and connect them to the procedure of inference execution, so that it will be feasible to do so with a computer. This order is given as a list or system of rules (rule block), [9], [10].

We applied FuzzyTech software, [11]. In the first phase (Rule block 1, Rule block 2), 144 rules in each block are automatically created. Some of them are represented in Tables 1 and 2. In block 3 and the block 4, FuzzyTech software creats 15 rules (Tables 3 and 4).

***Table 1**: Some rules of the Rule Block "RB1"*

IF					THEN	
DENSITY_01	MARKET	PRICE	SEASON_01	UNCERTAIN	DoS	DEMAND
WEAK	BIG	HIGH	LOW	BIG	1.00	HIGH
WEAK	BIG	HIGH	LOW	MEDIUM	0.01	HIGH
WEAK	BIG	HIGH	LOW	VERY_BIG	1.00	HIGH
WEAK	BIG	HIGH	HIGH	SMALL	0.00	MEDIUM
WEAK	BIG	HIGH	HIGH	BIG	0.00	LOW
WEAK	BIG	HIGH	HIGH	MEDIUM	1.00	LOW
WEAK	BIG	HIGH	HIGH	VERY_BIG	0.00	LOW
MEDIUM	SMALL	LOW	LOW	SMALL	0.91	LOW
MEDIUM	SMALL	LOW	LOW	BIG	1.00	LOW

***Table 2**: Some rules of the Rule Block "RB2"*

IF					THEN	
COSTS	POLICY	SEASON_02	UNCERTAIN	WEATHER	DoS	PRODUCTIC
NORMAL	GOOD	HIGH	VERY_BIG	BAD	1.00	MEDIUM
HIGH	BAD	LOW	SMALL	GOOD	1.00	LOW
HIGH	BAD	LOW	SMALL	BAD	1.00	MEDIUM
HIGH	BAD	LOW	BIG	GOOD	1.00	LOW
HIGH	BAD	LOW	BIG	BAD	1.00	MEDIUM
HIGH	BAD	LOW	MEDIUM	GOOD	1.00	LOW
HIGH	BAD	LOW	MEDIUM	BAD	1.00	LOW

***Table3:** Rules of the Rule Block "RB3"*

IF		THEN	
DEMAND	PRODUCTION	DoS	SUPPLY
VERY_LOW	LOW	1.00	VERY_LOW
VERY_LOW	MEDIUM	1.00	LOW
VERY_LOW	HIGH	1.00	MEDIUM
HIGH	LOW	1.00	VERY_LOW
HIGH	MEDIUM	1.00	LOW
HIGH	HIGH	1.00	HIGH
LOW	LOW	1.00	LOW
LOW	MEDIUM	1.00	MEDIUM
LOW	HIGH	1.00	HIGH
MEDIUM	LOW	1.00	LOW
MEDIUM	MEDIUM	1.00	HIGH
MEDIUM	HIGH	1.00	VERY_HIGH
VERY_HIGH	LOW	1.00	MEDIUM
VERY_HIGH	MEDIUM	1.00	HIGH
VERY_HIGH	HIGH	1.00	VERY_HIGH

***Table 4:** Rules of the Rule Block 'RB4'*

IF		THEN	
PRODUCTION	SUPPLY	DoS	CAPACITY
LOW	VERY_LOW	1.00	EXTR_HIGH
MEDIUM	VERY_LOW	1.00	MEDIUM
HIGH	VERY_LOW	1.00	LOW
LOW	LOW	1.00	EXTR_HIGH
MEDIUM	LOW	1.00	MEDIUM
HIGH	LOW	1.00	HIGH
LOW	MEDIUM	1.00	MEDIUM
MEDIUM	MEDIUM	1.00	LOW
HIGH	MEDIUM	1.00	HIGH
LOW	HIGH	1.00	MEDIUM
MEDIUM	HIGH	1.00	HIGH
HIGH	HIGH	1.00	VERY_LOW
LOW	VERY_HIGH	1.00	LOW
MEDIUM	VERY_HIGH	1.00	HIGH
HIGH	VERY_HIGH	1.00	VERY_LOW

3.3 Defuzzification

Defuzzification is the conversion of a given fuzzy quantity to a precise, crisp quantity. There are many procedures for defuzzification, which give different results. In our example, the fuzzy model is created with FuzzyTech 5.55i software, and we use the Centre of Maximum (CoM) defuzzification method.

3.4 Optimisation

When the system structure is set, and membership functions and rules in all the rule blocks are defined, the model must also be tested and checked.

During optimization, the entire definition area of input data are verified. For optimisation, there are various methods. One of the most efficient methods is using neural nets during the neuro-fuzzy training to obtain good and regular results.

4 NUMERICAL EXAMPLE

Starting with the fuzzy model using FuzzyTech software, we can simulate all possible situations interactively.

Subsystems 1 and 2 are independent, and numerical examples can be made separately. Because subsystems are one-phased, neurofuzzy training can be used for each of them.

Some results are given in Tables 5 and 6.

Table 5: *Some numerical results of the subsystem 1*

DENSITY_01	MARKET	PRICE	SEASON_01	UNCERT_01	**DEMAND**
10	10	10	10	10	**38**
50	70	30	50	40	**62**
80	20	50	80	80	**46**
30	50	90	30	30	**45**
60	80	80	40	50	**59**
100	100	80	60	90	**44**
30	80	20	80	20	**61**
40	40	40	40	40	**65**
60	60	50	50	20	**67**
100	100	2	100	2	**100**

Table 6: *Some numerical results of the subsystem 2*

COSTS	POLICY	SEASON_02	UNCERT_02	WEATHER	**PRODUCTION**
10	10	10	10	10	**46**
50	50	50	50	100	**67**
100	1	1	100	1	**0**
50	60	80	20	50	**57**
70	60	100	20	50	**60**
80	80	30	60	60	**50**

80	30	30	60	60	**34**
30	80	80	10	50	**70**
30	80	90	50	100	**82**
30	80	90	60	80	**71**

With the interactive simulation, made possible by using FuzzyTech software, every situation can be simulated. The quality of the results depends on the expert who prepares a data file for the neuro-training procedure.

After optimizing both of the subsystems in phase 1, the entire fuzzy system can be run in all three phases. Some numerical results are presented in Table 7.

Table 7: *Some numerical results in three-phased fuzzy system*

DENSITY_01	10	20	30	50	60	80	80	80	100	100	5
MARKET	10	40	40	20	80	80	50	50	50	100	5
PRICE	10	40	80	80	90	20	20	40	70	5	100
SEASON_01	10	10	20	20	50	50	80	80	60	100	5
UNCERTAINTY_01	10	40	40	80	80	50	50	20	20	5	100
DEMAND	38	41	37	40	45	61	61	53	57	100	2
COSTS	10	60	60	80	80	20	20	50	50	5	100
POLICY	10	50	50	20	20	80	80	40	40	100	5
SEASON_02	10	80	80	50	50	40	40	90	90	100	5
UNCERTAINTY_02	10	30	30	50	80	80	20	50	60	5	100
WEATHER	10	10	80	80	40	40	70	80	90	100	5
PRODUCTION	50	40	56	43	32	50	65	57	50	100	0
SUPPLY	**41**	**33**	**42**	**40**	**34**	**45**	**50**	**47**	**42**	**100**	**0**
(weighted)	**51**	**41**	**49**	**48**	**41**	**52**	**57**	**54**	**49**	**100**	**0**
CAPACITY	**40**	**47**	**43**	**43**	**49**	**42**	**37**	**40**	**43**	**0**	**100**
(weighted)	**49**	**59**	**51**	**52**	**59**	**48**	**43**	**46**	**51**	**0**	**100**

The data in the rows SUPPLY and CAPACITY are the basic information about the behaviour of our fuzzy system.

For the extreme situations given in (data) columns 10 and 11, it can be observed that if demand is very big (maxima 100 units), and current production is zero then (of course) the supply from

current production is zero and we have to activate stocks (extra capacities) in all 100 units; if demand is very small (near 0 units), and production is zero, then all demand is satisfied from stocks.
Other results yield similar information. For example, in the first (data) column we have with respect to the conditions for demand and for current production, weighted supply from current production 51 units. In the case of the "negative" supply, we can activate stocks (i.e. additional capacities) in the other 49 units of goods.

5 CONCLUSION

The fuzzy mathematical model of system control can be used in an energy technology system and in its subsystems. During the control process, a great deal of information must be processed, which can only be done if a transparent and properly developed information system is available. The solution depends on many numerical parameters. All data and numerical analysis can only be processed into information for control if high quality and sophisticated software and powerful hardware are available.

The fuzzy approach in creating the mathematical model with which we are describing the system can be successful if we have a good robust base of expert knowledge for neural training. Experts can use fuzzy models for real numerical predictions.

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WIND ENERGY IN SLOVENIA AND AUSTRIA

VETRNA ENERGIJA V SLOVENIJI IN AVSTRIJI

Iztok Brinovar[ℜ]

Keywords: wind power, wind energy, wind farm, renewable energy sources

Abstract

Due to obvious climate changes and increasing needs for electrical energy, increasing attention is dedicated to the use of renewable energy sources, which include wind energy. This article presents the current situation of wind energy exploitation in Slovenia and Austria and their national objectives for the near future. In contrast to Slovenia, Austria has a long tradition of wind energy use, due to its high wind energy potential. As member states of the European Union, Slovenia and Austria follow the European energy policy and its objectives of sustainable, competitive, and secure supplies of energy. This article deals with Slovenian and Austrian national energy policies and their incentive programs that encourage the exploitation of wind energy and other renewable energy sources. Both countries are increasing their renewable energy production by implementing financial support mechanisms, mostly feed-in tariffs, premium tariffs and loans.

Povzetek

Zaradi vse bolj očitnih klimatskih sprememb ter vedno večjih potreb po električni energiji je vedno več pozornosti namenjene uporabi obnovljivih virov. Med obnovljive vire energije uvrščamo tudi vetrno energijo. V članku je predstavljeno trenutno stanje glede izkoriščenosti vetrne energija v Sloveniji in Avstriji ter predstavljeni nacionalni cilji za prihodnost. V primerjavi s Slovenijo ima Avstrija dolgo tradicijo izrabe vetrne energije zaradi velikega vetrnega potenciala. Kot članici Evropske unije Slovenija in Avstrija sledita evropski energetski politiki in njenim ciljom trajnostne, konkurenčne in varne oskrbe z energijo. V drugem delu članka je posledično predstavljena tudi slovenska in avstrijska nacionalna energetska politika ter finančni podporni mehanizmi, ki spodbujajo izrabo vetrne energije in drugih obnovljivih virov. Obe državi spodbujata izrabo obnovljivih virov z uvedbo finančnih podpornih,

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mehanizmov, predvsem z zagotovljenimi odkupnimi cenami električne energije, obratovalnimi podporami in krediti.

1 INTRODUCTION

At present, electrical energy production has a pronounced role and a strong influence on the entire environment. Current trends in energy supply and use are economically, environmentally, and socially unsustainable. The European Union has set itself a goal of generating 20% of energy consumption from renewable energy sources (RES) by 2020. The introduction of sustainable and low-carbon energy technologies is crucial for the transition to a low-carbon society. As an alternative to fossil fuels, RES also contributes to the reduction of greenhouse gas emissions, the diversification of energy supplies, and the reduction of dependency on fossil fuel markets, [1,2].

To achieve the European energy policy goals, the introduction of financial support mechanisms for the promotion of RES is essential. Starting a wind power plant requires a significant amount of research, start-up capital and development. Since the efficiency of a wind power plant depends on its correct placement in the environment and local wind conditions, the precise assessment of wind resources in a certain area is the key element in successfully establishing an economically viable wind power plant. In the previous decade, the share of wind energy production has been increasing rapidly, [3].

The next chapters of this article present the current situation of wind energy exploitation in Slovenia and Austria, their national objectives for the near future, their energy policies, and their incentive programs that encourage the exploitation of wind energy and other RES.

2 WIND ENERGY IN SLOVENIA

2.1 National progress and objectives for wind energy

Slovenia does not have strong and constant winds. Higher velocities are evident in the mountainous part of Slovenia, particularly with the wind called “Burja” in the wider coastal area. It is an inconsistent and gusty wind, which is not suitable for exploitation of wind energy, [4].

Maximum wind speeds in Slovenia appear in spring and autumn. Figure 1 shows the average annual value of wind velocity at an elevation of 10 m.

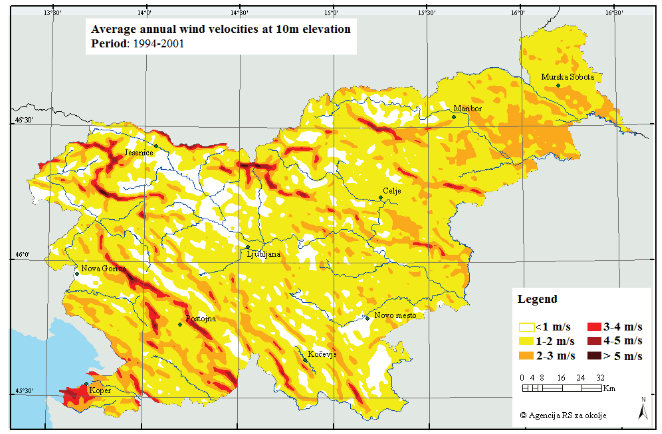

Figure 1: *Average annual wind velocities measured at 10 m elevation,* [5]

For most places in Slovenia, the average annual wind velocities are between 1 to 3 m/s, which is also not suitable for the exploitation of wind energy; only at higher altitudes are average annual wind velocities higher [6].

The Slovenian National Renewable Energy Action Plan (NREAP) plans the integration of wind power plants with an installed power of 106 MW by the end of 2020. Currently, the installed power capacity of wind power plants greatly lags behind the action plan. According to statistical data, there are officially only two operating wind power plants in Slovenia with a total power of 3.2 MW. In previous years, there was also a project called “Volovja reber” for the construction of 33 wind power plants, but it has failed because of environmental issues, [1].

The first wind power plant, named “Marjetica”, was built in June 2013 and is located in the village of Dolenja vas pri Senožečah. With an installed capacity of 2.3 MW, Marjetica has a three-bladed turbine with a diameter of 71 metres mounted on a 98-meter high tower. The wind turbine of type E-70 from a German manufacturer is owned by the company Alpen Adria Energie d.o.o., which is planning to build a large wind park in the vicinity of the existing power plant. The estimated annual production of the power plant is 4.5 GWh, which is enough to supply electrical energy to 1154 households. The total value of the investment amounts to 3 million euros, [7,8].

The second wind power plant is located at the foot of the Nanos mountain near the village of Razdrto; it was built in the spring of 2014 and is ranked among the smaller wind power plants. The diameter of a rotor from the Enercon E-44 wind turbine is 44 metres, and the rotor swept area is 1521 square metres. The three bladed rotor is made of high-quality glass-fibre reinforced plastic (GFRP). The rated power output is 900 kW. The Enercon E-44 has a steel tube tower with a height of 53 metres and a direct-drive synchronous generator. The average annual wind speed at the site is 6.43 m/s which enables the operation of the wind turbine near the optimal power coefficient. The estimated annual production of the power plant is 1.67 GWh, which is enough to supply electrical energy to 500 households, [9,10,11].

Figure 2 shows the characteristics of Enercon E-70 and E-44 wind turbines. A 3-D model of the wind turbine is presented on the left, and a photograph of the Marjetica wind turbine on the right.

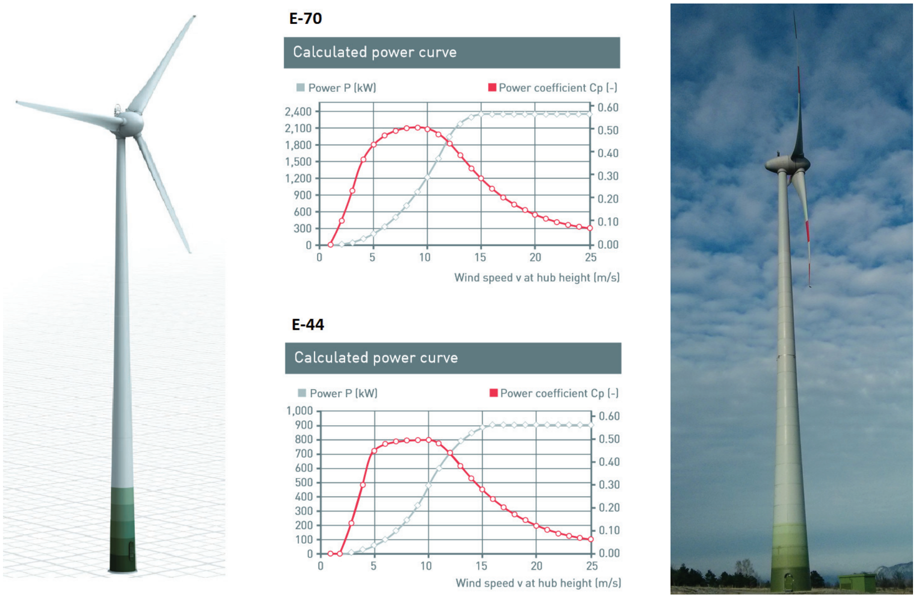

Figure 2: *Enercon E-70 and E-44 wind turbines,* [11,12]

Considering the current complications associated with the placing of wind power plants in the Slovenian environment, special attention should also be given to environmental issues, the appropriate management of projects, especially cooperation with the public and the decision-making process, [1].

2.2 National energy policy

As a member of the EU, Slovenia follows the European energy policy and its objectives of a sustainable, competitive and secure supply of energy. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from RES and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC provides that each Member State must adopt a national renewable energy action plan for the 2010-2020 period. These plans must set out the national targets of Member States for the shares of gross final energy from RES consumed in transport, electricity and heating and cooling in 2010, [13,14].

The Parliament of the Republic of Slovenia adopted a new Energy Act in 2014 (EZ-1, Official Gazette of the Republic of Slovenia No. 17/2014). This act establishes a legal framework for electrical energy generated from RES and transposes into Slovenian legislation several European directives and regulations relating to the energy market, energy efficiency and RES. It determines the principles of energy policy, the operating rules of the energy market, implementation methods and forms of public utilities in the energy sector, principles and measures for achieving reliable energy supply, for increasing energy efficiency and the use of energy from RES, it determines the conditions for the operation of energy facilities, and it regulates the competence, organization and functioning of the Energy Agency and the competencies of other authorities performing tasks under this act, [15,16].

In addition to the Energy Act, also noteworthy are the NREAP, the National Energy Efficiency Action Plan (NEEAP) and the Resolution on the National Energy Programme (ReNEP), which coordinates the functioning of institutions dealing with energy supply and determines the goals and mechanisms for the transition to a low-carbon society by 2030. With NEEP, in accordance with the requirements of the Energy Efficiency Directive (2012/27/EU), Slovenia raises the national objective of improving energy efficiency by 20% by 2020.

Slovenia also has a Decree on Support for Electricity Generated from RES (Official Gazette of the Republic of Slovenia, No. 37/2009). This decree includes provisions on financial support for system operators generating electricity from RES, on the relations between system operators and grid operators, and on the calculation of the uniform annual price and the uniform annual premium, [17].

2.3 Incentive programs

Most European Union member states increased their renewable energy production by implementing support policies, mostly feed-in-tariffs (FIT), premium tariffs and loans.

Pursuant to the Energy Act, a financial support mechanism has been established in Slovenia for producers of electrical energy from RES, which allows the selection between two types of supports. The Decree on Support for Electricity Generated from RES provides the mechanism for obtaining the support. Electrical energy generated from RES is supported mainly through a guaranteed feed-in tariff ("guaranteed purchase price") and a premium tariff (a "financial operating aid"). Qualified producers of electrical energy from RES can choose between a guaranteed FIT and a financial operating aid in addition to the electricity price achieved in the energy market. The producer is entitled to receive one or the other type of support, but cannot receive both at the same time. In Slovenia, all renewable energy generation technologies are generally eligible for support, with some exceptions for certain technologies in terms of system capacity limits. To obtain support, producers need to prove that electricity has been produced from RES through guarantees of origin and that the plant is operating in compliance with regulatory requirements. The Slovenian Energy Agency issues the guarantees of origin upon a producer's request. Support may be granted for a maximum period of 15 years or for a shorter period, depending on when the plant became operational for the first time, [15,18].

The ReNEP provides a number of measures and instruments to increase the share of RES. Pursuant to ReNEP, public calls for grant applications are organised in Slovenia, and loans are provided for renewable energy projects. The Ministry of the Economy invites applications for subsidies, and the Slovenian Environmental Fund (Eco Fund) provides financing opportunities with lower interest rates for investments in RES. The Eco Fund's main purpose is the promotion of development in the field of environmental protection, [15,18,19].

Table 1 shows the Slovenian FIT and premium tariff prices for 2014 and 2015 for electrical energy generated from wind power plants, depending on the power capacity of a wind turbine. The FIT price for 2015 for micro, small and medium wind power plants is fixed at €95.38/MWh, and it is equal to guaranteed purchase prices in previous years. Wind power plants larger than 10 MW are not eligible to receive FIT support, but can only receive financial operating aid, [20].

Table 1: *FIT and premium tariff prices for 2014 and 2015* [20]

	2014		2015	
	FIT price (€/MWh)	Premium tariff price (€/MWh)	FIT price (€/MWh)	Premium tariff price (€/MWh)
Micro >50 kW, 50 kW>Small>1 MW, 1 MW>Medium>10 MW	95.38	60.73	95.38	63.66
10 MW>Big>125 MW	not eligible	49.49	not eligible	52.64

3 WIND ENERGY IN AUSTRIA

3.1 National progress and objectives for wind energy

Austria is among the global leaders in energy production from RES with nearly 70% of renewable energy in its electricity mix. In contrast to Slovenia, Austria has a long tradition of wind energy use, due to its high wind energy potential. The Austrian wind power supplier industry is also globally leading in the fields of the wind power generators, control units and design. Table 2 shows Austria's key statistics in 2014. The large expansion of wind power installations started in 2012 due to an amendment to the Austrian Green Electricity Act (GEA), which is described in detail in the next chapter. Since then, the number of wind power installations has increased by more than 300 MW every year with a record 411 MW installed in 2014. By the end of 2014, approximately 2095 MW of wind power were operating in Austria. An additional 391 MW of wind power installations were constructed in Austria in 2015. The majority of wind turbines are located in Lower Austria (963 MW), Burgenland (962 MW), followed by Styria (121 MW), Upper Austria (41 MW), Vienna (7,4 MW) and Carinthia (0.5 MW). Figure 3 shows the cumulative installation of wind power in Austria, [21,22].

Table 2: *Key national statistics 2014,* [22]

Total (net) installed wind capacity	2095 MW
New wind capacity installed	411 MW
Total electrical output from wind	4.5 TWh
Wind generation as percent of national electric demand	7.2%
Average national capacity factor	24%
Target:	3000 MW wind power by 2020

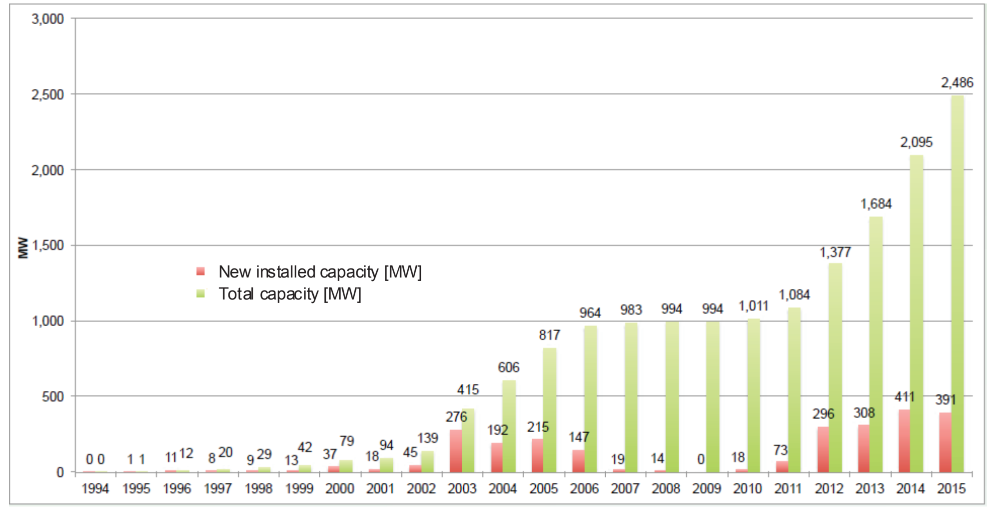

Figure 3: *Cumulative installation of wind power in Austria,* [22]

The most common suppliers of wind turbines in Austria are the companies Enercon and Vestas. Two of the largest wind turbines in the world E-126 models with a power capacity of 7.5 MW each were built by Enercon and Energie Burgenland Windkraft GmbH.

3.2 National energy policy

Austria, as a member of the EU, also follows the European energy policy and its objectives of a sustainable, competitive, and secure supplies of energy. As with other EU member states, Austria has also adopted NEEAP and NREAP, which propose concrete measures for achieving renewable energy targets and for increasing energy efficiency in different areas. The Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management has published the Resource Efficiency Action Plan (REAP) in early 2012. REAP provides an analysis of recent resource efficiency trends and sets medium and long-term national targets for increased resource efficiency.

The large expansion of wind power installations in Austria started in 2012 and was launched by the Austrian Green Electricity Act (GEA or Ökostromgesetz). It entered into force in 2003, was amended in 2009 and again in 2011. The main objectives of this act are, [15,22,23]:

- contribution to the EU 20-20-20 target,
- promotion of RES and new technologies,
- to increase the capacity of renewable energy power plants,
- to provide investment protection for future and existing power plants.

As previously mentioned, the Austrian parliament adopted legislation in 2011 for electricity from RES, known as GEA 2012. It entered into force on 1 July 2012 and established a new long-term target of reaching a total wind power capacity of 3000 MW by 2020, which is even higher than Austria's target for wind energy in NREAP. In 2014, Energiewerkstatt, an Austrian consultant, conducted a study and estimated that a total wind power capacity of 3808 MW can be achieved by 2020, followed by a total capacity of 6649 MW in 2030, [15,22,23].

3.3 Incentive programs

The GEA 2012 established a stable legal framework through 2020 and established a so-called FIT system for renewable energy, which is a support mechanism, a tariff support intended for green electricity producers. The GEA 2012 obliges the so-called Green Electricity Settlement Centre-OeMAG (Ökostromabwicklungsstelle) to purchase green electricity from eligible generators at fixed FIT prices. The Green Electricity Settlement Centre then attributes the purchased electricity to electricity traders, who are legally obliged to buy the attributed electricity at a fixed transfer price. The Green Electricity Settlement Centre is also responsible for giving contracts to green electricity producers as long as there are enough funds for new projects. In other words, the Green Electricity Settlement Centre is the institution that is in charge of buying green electricity at the FIT and selling it to the electricity traders, [15,22,23].

The FIT is set by an ordinance and is not fixed in the GEA 2012 itself. The FITs are fixed in the Green Electricity Regulation by the Minister of Economy in accordance with the Minister of Environment and the Minister of Social Affairs. The tariffs are guaranteed for 13 years. The purchase obligation is limited to a specific amount of capacity (depending on the available funds for new projects). In Austria, currently 1555.4 MW are supported by a FIT under the Green Electricity Regulation [15,22,23].

Figure 4 shows the Slovenian and Austrian FIT prices from 2010 to 2015. The FIT for 2010 and 2011 was fixed at €97.00/MWh, for 2012 it was fixed at €95.00/MWh, for 2013 it was fixed at €94.50/MWh, for 2014 it was fixed at €93.60/MWh and for 2015 it is fixed at €92.70/MWh. For 2016, the FIT has to be set by a new ordinance.

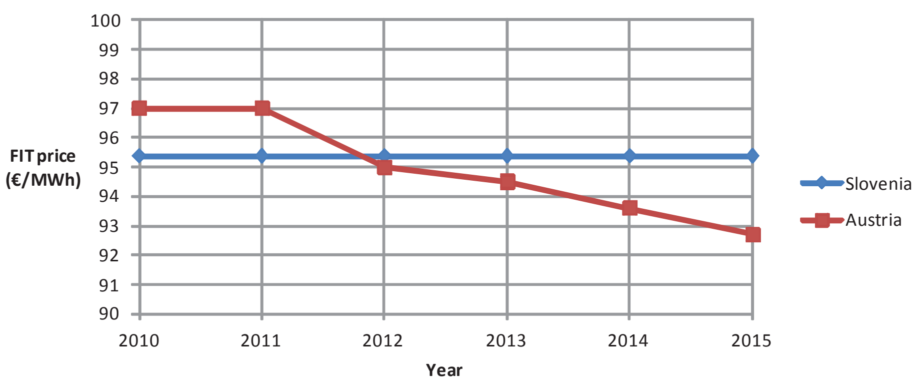

Figure 4: *Slovenian and Austrian feed in tariff prices from 2010 to 2015*

Until 2012, the Austrian FIT prices were higher than Slovenian FIT prices. Since then, the Austrian FIT prices have been reduced each year while Slovenian FIT prices remained fixed at €95.38/MWh during the whole period from 2010 to 2015.

4 CONCLUSION

The natural conditions for RES differ across Europe. As already mentioned, Slovenia is not a country with strong and constant winds. It is characterized by lower average annual wind speeds (with average annual wind velocities between 1 and 3 m/s), which are not suitable for the exploitation of wind energy, since the average wind speed is lower than the cut-in speed of a wind turbine, which is typically between 3 and 4 m/s, [24]. Only at certain micro-locations and at higher altitudes are average annual wind velocities in Slovenia higher. It would be advisable to carry out a study of the geographical distributions of wind resources on these micro-locations and examine the possibilities for the exploitation of wind energy. According to [4], Slovenian wind power production could also increase by taking advantage of already degraded areas, such as land along roads, industrial areas, bridges, etc., and by raising public awareness concerning wind energy. In the future, Slovenia should also investigate the use of small wind turbines in urban areas.

In contrast to Slovenia, Austria has a long tradition of wind energy use, due to a high wind energy potential. Slovenia has 3.2 MW of wind power installations while Austria has a total of 2486 MW of wind power installations. Since 2012, the number of wind power installations in Austria has increased by more than 300 MW every year. Austria is thus making good progress towards their RES targets concerning wind energy. The stability of the incentive program, the amounts of the FIT, and the annual amount of funding for new projects are essential for the growth of wind power capacity, [22].

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