Optimization of wind energy conversion systems

Optimizarea sistemelor de conversie a energiei eoliene

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Abstract. *In close connection with the issue of global security, the issue of ensuring energy resources has been put on the table of consumers and producers of various forms of energy, researchers, but especially politicians and social planners. Ensuring energy independence was put into question after the onset of the oil crisis in 1973, thus the various energy sources and their associated technologies are gradually being replaced by new technologies that integrate renewable energy sources, capable of taking over at an increased level of efficiency the energy requirement.*

Key words: optimization, storage, energy, wind, RES,

1. Introduction

Even if the world's energy resources are enormous, capital resources are limited, which makes the exploitation of these energy resources not accessible even to developed countries, even more so to developing or underdeveloped countries. The solution to the world energy problem depends on political, cultural, economic, geographical, and technical circumstances. The formulated energy programs are shown to be the result of scenarios regarding primary resource provision options and appear to be a response to the current crisis. In reality, the energy scenario for the 2030s is based on the penetration models of new energy technologies [1]. The success of new energy technologies depends on how and in what time they will prove their technical-economic feasibility. The global dimension of the energy problem is obvious, the 1970s led to an increase in the price of oil (Fig. 1), putting in the background the fact that the energy problem must be approached starting from themes such as: resource conservation, the development of new technologies, reducing the impact on the environment, in other words the chance of a future depends on the range of actions taken today.

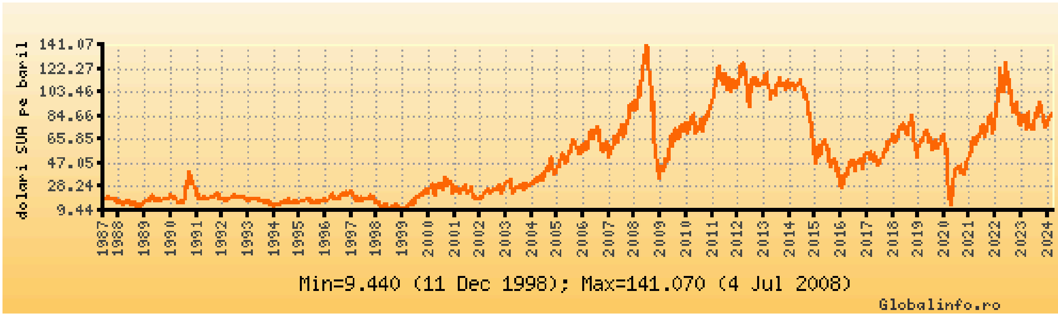


Fig. 1. The history and graphs of the international spot quotations of the barrel of oil [2].

The energy problem between demand and conservation it isdiscussed, also considering population growth, Fig. 2.

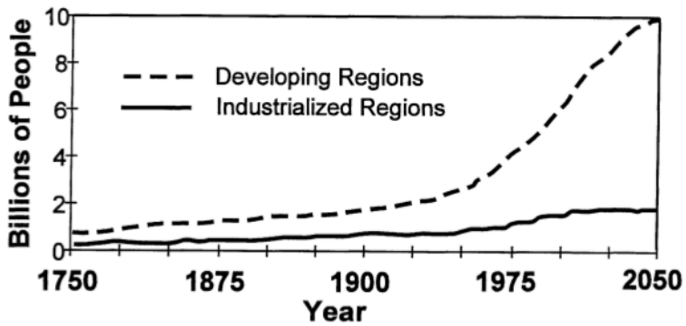


Fig. 2. World population. Projections until the year 2050 [3]

The provision of energy resources to meet energy needs as a result of population growth and technological progress (progress considered energophagous), must be subject to constraints regarding: the time in which a new technology can replace an existing technology, climate change risks, risks regarding the construction of energy capacities, but also risks of a political nature and, more recently, risks of a military nature.

Meeting the demand for energy as a result of the growth of the world population can be achieved either by developing nuclear capacities, or by adopting a nuclear moratorium, and certainly by reducing consumption, in which case is mandatory the development of SRE conversion and storage systems.

Romania was not indifferent to the effects of the oil crisis of the 70s, it can be considered that it understood that the energy future is represented by a mix in which RES must also be part. In this sense, at the beginning of the 80s, important research centers in Romania under the coordination of the Research Center of the Traian Vuia Polytechnic Institute in Timisoara started an extensive project to exploit the wind potential on Mount Semenic [4], and before 1989, Timişoara had the first neighborhood that was supplied with domestic water prepared with the help of solar energy. [5].

Analyzing the renewable energy potential of Romania, it can be found the existence of 5 areas with a photovoltaic potential between 1000 and 1400 kWh/kWp

[6] and also an important wind potential with average wind speeds at heights of 10m, 50m and 100m, between 4.09-7m/s [7].

The multidisciplinary nature of the energy issue, the transition to new technologies for the use of RES, the reduction of energy consumption in production processes and in residential buildings through energy efficiency [1], leads to the promotion of a vigorous energy mix program.

2. Analysis of the optimization possibilities of the wind power plant from Oravița, Caraș Severin county

Analyzing the state of the national energy system (NES) in the period 01.01.2023-31.01.2023, it can be seen that a negative balance is recorded through the contribution of hydropower (Fig. 3)

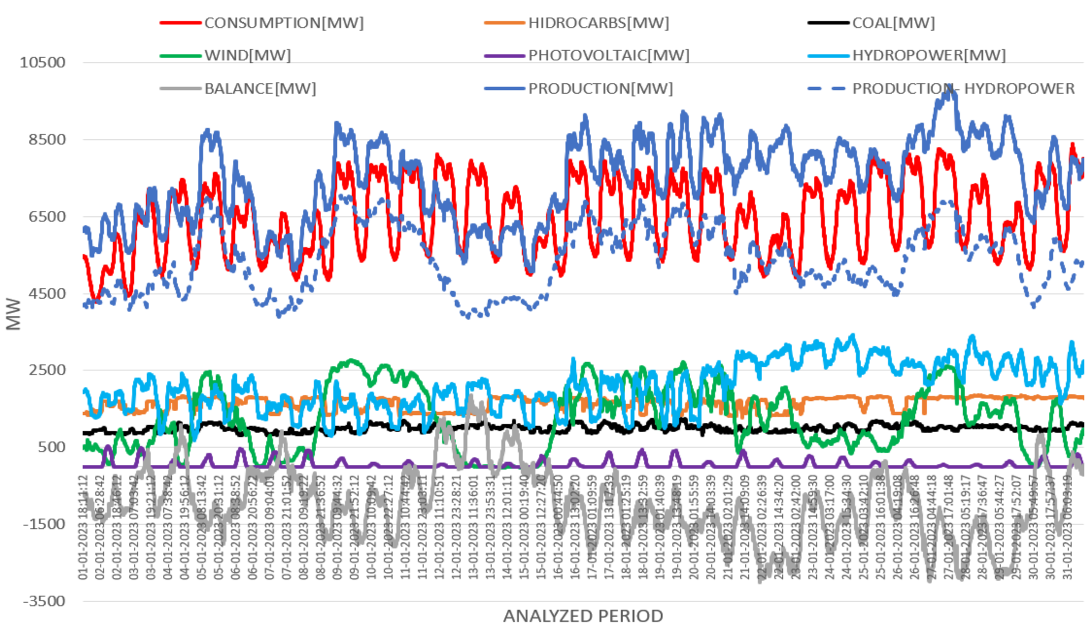
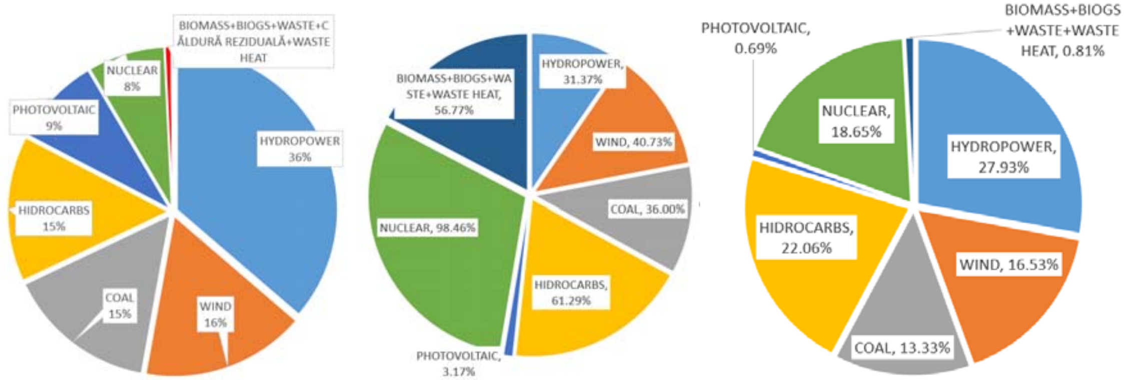


Fig. 3. State of the NES [8]

The share of the types of sources that make up the energy mix (Fig.4. a) indicates that most of the electricity production capacities are below the value of the installed power (Fig.4. b).

As expected, the predictable nature of the areas of the production curve where the sun is not in the sky (between sunset and sunrise) and the unpredictable nature of wind systems (Fig. 3), which still had a contribution of 16.53% in the energy mix in the analyzed period.



a) b) c)

Fig. 4. The share of the types of sources in the energy mix

a) Installed power [9], b) System status in the period 01.01.2023-.31.01.2023

Without knowing the reasons, we consider it inadmissible not to cover the power gap in the interval in which a positive balance is registered (Fig. 3).

The unpredictability of RES is accepted, it is also known that energy transactions on the stock market are dictated by the mechanisms of the imperfect economy, but we consider inadmissible the dispatching of NES by which hydropower is not properly exploited given that it represented 27.93% of the total energy produced in the analyzed period. In other words, it did not fulfill the role of regulating the load curve in its entirety, thus contributing to maintaining a high price of electricity.

It is also known that the non-functioning of hydropower production capacities depends on maintaining the level in the reservoirs and may be dictated by objective factors (lack of precipitation, scheduled overhauls) but especially by subjective factors (price of electricity, breakdowns because of maintenance inadequate, much too long times for repairs). The first objective cause must be eliminated if we follow Fig. 5

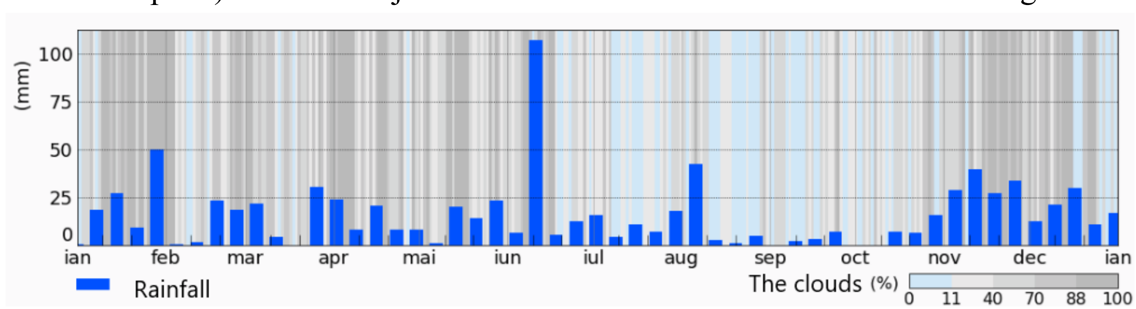


Fig. 5. Amount of precipitation in 2023 [10]

Analyzing the curve of production, consumption, and the balance in Fig. 6, it is found that hydropower covers the power gap until sunrise, without being able to explain why it does not cover this gap after dark.

The fact that the renewable energy potential of Romania is insufficiently exploited is illustrated in Fig. 4.a). It is also known that the renewable potential cannot be exploited in a large percentage if there are no means to cover the power gaps, in other words, without storage capacities.

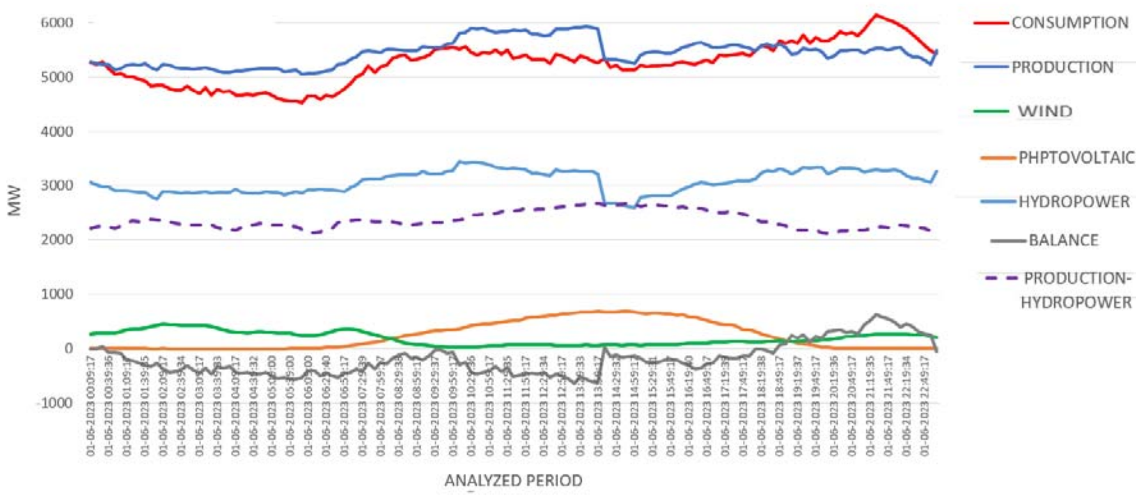


Fig. 6. State of the NES 01.06.2023- 30.06.2023 [8]

It is also known that the renewable potential cannot be exploited in a large percentage if there are no means of covering power gaps, in other words, in the absence of storage capacities.

The specialized bibliography, including [11], proposes a multitude of electrical energy storage procedures, while the optimal solution must be chosen according to the size and specificity of the production, transport/distribution, and use of electrical energy systems.

The article proposes a point of view on the optimization of wind power plants (WPPs) by storing surplus energy in hydraulic energy.

The WPPs hybrid system combined with pumped hydroelectric power plants (PHPPs), presents the advantage of storing amounts of energy of the order of GWh, at a circulation of powers up to 1GW and with storage periods of hours, days or even seasonal storage [11], [12]. These storage systems can successfully supply the power gaps and can also be frequency regulation systems of the power system.

Even if the storage technology is known, the capital problems, the geographical ones, which overlap with the actions of environmental activists, the costs related to the transport of electricity and the efficiency of pumping slow down for the moment the realization of SHPs coupled to SRE.

The specialized literature deals in numerous reviews from simple solutions for storing the electrical energy produced/that can be produced, in the potential energy of water to be used in periods of power gap [13, 14], to systems bolder underground pumped storage where hydraulic energy is stored in a cavity (obtained from impermeable materials) placed underground by raising the soil covering this cavity [15].

Particular attention is paid to low head storage systems as a result of research in the field of high head storage and tide conversion technologies [16], of cascaded storage systems which have the advantage of reduced evaporation and therefore an increase in efficiency of approx. 15% compared to classic systems with lower tank and upper tank [17].

The dynamic regime in which the wind turbines operate poses problems regarding the full exploitation of the wind energy, since the maximum conversion of the wind energy can be done according to Eq (1).

$$MPPT=f(\omega_{opt}) \quad ...(1)$$

The generator load regulation algorithm at variable wind speeds is based on the regulation algorithms based on the turbine rotor kinetic energy in which the dual-fed induction rotor regulation system of the asynchronous generator performs the regulation load of the pumping system which is driven with using a synchronous machine with permanent magnets [18].

The article proposes an optimization solution for the WPPS Oravița, Caraș Severin county, starting from the renewable potential of the area, the power installed in SRE and the possibilities of electricity storage.

In the area there is a WPPS with a total installed power of 9MW, composed of 6 wind turbines with 3 blades (LCB1…LCB6) with a hub height of 110m, with an installed power of 1.5MW/turbine (Fig.7).

Fig. 7. Location of the Oravita wind power plant [19]

WPPS is installed in an agricultural area (low roughness), the prevailing wind direction is SE, the wind speed varies between 3.65 m/s to 6.36 m/s (the minimum speed of 3.65 m/s is slightly more higher than the typical speeds of low-speed wind turbines), Table 1.

Table 1

Wind speed [19]

Height (m)	Mean wind speed (m/s)	Maximum mean wind speed (m/s)	Maximum wind speed (m/s)
51.5	4.64	27.09	35.45
49	4.6	27.1	35.85
40	4.447	26.49	36.21
10	3.4	20.94	31.74

According to equation (2) the power of a wind turbine is profoundly influenced by the wind speed.

$$P=\frac{1}{2}\cdot\rho\cdot\cdot C_\rho\cdot A\cdot v^3 \qquad (2)$$

Where, wind turbine power (P) in W, air density (ρ) in kg/m^3, gravitational acceleration (g) in m/s^2, area swept by wind turbine blades (A) in m^2, turbine power coefficient (Cp) , wind speed (v) in m/s.

From the analysis of Table 1 and Fig. 8, it is observed that in the absence of storage when the optimal angular speed is exceeded, when the price of electricity is low, or when the demand for electricity is low, the wind turbine / WPPS is stopped, potentially causing significant financial losses.

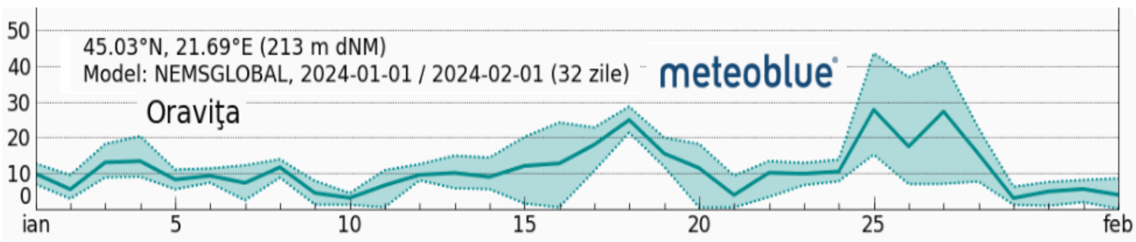


Fig. 8. Wind speed in Oravita, January 2024 [10]

A maximum capture of wind energy can only be achieved on the basis of a mathematical model that takes into account the variation of wind speed, the inertia of the turbine rotor, the mechanical stresses and even the geometry of the turbine that changes over time. This is practically impossible without storage.

Capturing the energy of the maximum wind energy (at any value of the wind speed) is only possible if the electricity is charged in two directions: in the network at the value of the forecasted electric power and in a storage system capable of taking over the surplus energy produced regardless of the variations in wind speed over time.

The wind turbine will operate at the maximum power point (MPP), capturing maximum wind energy, regardless of the restrictions imposed by the National Energy Dispatcher.

The city of Oravița has two artificial lakes built between the years 1700 and 1750 for the purpose of providing drinking water and water for industry, regularizing floods, supplying water to a thermal power plant and for leisure (Fig. 9). The "Big" lake, with an area of 1.4 ha located at an altitude of 315 m, has a length of 230 m and a width of 120 m, a reception area of 9 km^2 and a volume of 133300 m^3. The dam has a height of 13.4 m, but currently has a high degree of silting. About 800m downstream, at an altitude of 285m, there is the "Small" Lake with a surface area of 0.2ha, a reception area of 10 km^2 and a volume of 43,000 m^3. The dam of approx. 9.6 m is in an advanced state of degradation with significant seepage.

Fig. 9. Oravița Valley [20]

Analyzing the variation of the wind speed and the existence of the two storage lakes at a distance of 5.1km from the WPPS, the optimization of the operation of the WPPS can be achieved through the construction of a hydroelectric power plant HPP for which different scenarios can be made.

Taking into account the storage capacity of the "Small" lake of 43000m^3, the energy accumulated in hydraulic energy can provide according to (Eq.3) a power equal to the installed power of the wind turbines for 1740s.

$$P=\rho\cdot g\cdot Q\cdot H\cdot \eta \qquad (3)$$

Where, electrical power (P) in W, water density (ρ) in kg/m^3, water flow in m^3/s, turbine head (H) in m, the conversion yield (η).

3. Conclusions

The wind system works optimally in terms of energy if it captures the maximum wind energy.

The stochastic character of SRE due to meteorological factors makes it impossible to fully exploit the renewable potential. If for solar systems the time interval in which these systems are not functional is known and measures can be taken to ensure the load curve by classic systems (coal, hydrocarbons), the grid coupling of WPPS registers great frequency assurance problems due to variable wind speed.

Expansion of the WPPS, including the exploitation of the offshore wind potential of the Black Sea is not possible without storage.

Although hydroelectricity storage has reached maturity, the implementation of storage capabilities is dependent on geographic conditions, capital resources, pumping costs, community acceptance, politic assumption, and regional instability.

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