MEASUREMENT OF NON-ELECTRIC QUANTITIES

COMPARATIVE ASSESSMENT OF RENEWABLE SOURCES FOR CRITICAL FACILITIES OF DECENTRALIZED SUPPLY

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Abstract. The concept of energy supply is widely discussed, but there is no consensus on ways of its provision. In the current research, we have provided an analysis of available combinations of renewable sources for decentralized energy supply. It is important for critical facilities on territorial society and district levels. The article considers the safety of the technical component of a complex organizational and technical system by studying the functional relationship between the parameters: temperature, time, active power, hydrogen participation, etc. The idea of the work is to evaluate the ratios of generating capacities of different types of renewable sources in complex systems and select highly efficient technologies and energy means for decentralized energy supply.

Key words: validation; deep well; geothermal energy; critical facility; energy supply.

1. Introduction

About 80 % of the world's population lives in countries that are energy importers. The direct use of electricity from renewable energy sources (RES) in transportation and thermal installations is envisaged. Hydrogen and its derivatives include synthetic fuel and feedstock, carbon capture and storage from point sources of fossil fuels, and other emissions-emitting processes, mainly in industry.

Enhanced National Determined Contributions and commitments made at COP26 demonstrate a promising trend but still fall short of what is required. The United Nations High-Level Dialogue on Energy in 2021 highlighted how far we are from realizing our pledge to ensure universal access to energy. The danger of pursuing false short-term solutions – such as turning back to coal, intensifying gas extraction, and engaging in new oil drilling – is palpable. According to the 2050 roadmap – tracking the progress of key components of the energy system to achieve the 1.5 °C target – geothermal energy consumption in direct end-use renewable energy should be scaled up 4-fold from 0.8 EJ in recent years to 4 EJ [1, 2]. The concept of energy security is discussed; consensus on ways of its providing is still absent though an overview of available indicators for long-term security of supply has been provided [3].

Energy facilities: NPPs, refineries, power lines, pipelines, etc. – are an example of a complex organizational and technical system, which consists of interconnected material objects (technical means and personnel ensuring their operation). That is a hierarchical human-machine complex that operates, realizing the achievement of announced goals. There are many high risks in this important sector of any country's economy. The rapid spread of other hydrogen energy technologies (fuel cells, hybrid engines, energy storage, etc.) is forecast. Under stringent climate policies, this diversification may not occur due to reduced demand for oil. Possible benefits of climate policy include powered fuel diversity and slower depletion of fossil resources

The main source of decentralized energy supply at crisis time for critical facility are renewable sources. Infrastructural facilities are becoming increasingly interconnected. So, it seems essential to develop models that account for interdependencies between infrastructure systems at different scales. These systems are considered as a network process of production, consumption, transshipment, and storage of resources (commodities), and connected by edges that capture commodity flows [4, 5]. The performance of the network under normal and extreme conditions model is described, and the performance of interdependent infrastructure systems (energy, water, and wastewater) by minimizing the cost of commodity flow is demonstrated, using Monte Carlo simulation [5].

The threat of leaving a carbon footprint of hydrogen synthesis should be eliminated, since instead of solving the problem of CO_2 emissions, they can simply be moved to another location. The possibility of creating an experimental plant based on an unused deep well, of which there are more than 150 in Ukraine, is considered. This would provide electricity and heat to the surrounding settlements. The daily energy surplus can be applied to produce green hydrogen. This increases the possibilities of decentralized energy supply and the security of operations in a crisis [6]. However, bear in mind that later studies have found that improving energy efficiency is a mandatory requirement for sustainable buildings by adopting measurements such as utilizing renewable energy sources, purchasing energy efficiency systems, using the materials & equipment for CO_2 emission reduction, and software for designing the buildings to reach a higher energy efficiency [7–11].

2. Drawbacks

Ukraine and the European Commission have signed a memorandum on a strategic partnership in the field of renewable gases, namely hydrogen and biomethane, and will jointly develop the production, trade, transportation, storage, and use of such gases [12]. The Memorandum envisages the exchange of information and assessments of scenarios and forecasts of demand for renewable gases; development of the regulatory field; harmonization of certification documents following EU requirements; identification and removal of barriers; infrastructure development; mobilization of financial and investment instruments; development of energy clusters in Ukraine.

The problem of sustainable energy self-sufficiency for rural residents, farms, and agricultural enterprises can be solved by local RES: solar, wind, energy crops, and crop residues. A promising area for accumulating energy from various types of renewable sources is the carbon-free technology of hydrogen production, simulta- neously transferring part of the generated electricity to the consumer grid and battery packs, depending on the generation and consumption balance [13].

3. Goal

The subject of the research is to study the efficiency of different types of renewable sources for decentralized energy supply and carbon-free hydrogen production technologies and the regularity of its impact on the process parameters.

4. Assembling research method

The National Joint Stock Company Naftogaz of Ukraine and the Ukrainian gas storage operator Ukrtransgaz have joined the H2EU+Store initiative, which involves the production of green hydrogen from renewable energy sources in western Ukraine. There is a possibility of storage in Ukrainian gas storage facilities (GSF) with subsequent export through gas pipelines to the EU, injection into GSF in Austria, and sale to con- sumers in Central Europe [14]. “H2EU+Store” is a comprehensive project that covers the production, transportation, storage, and supply of hydrogen to consumers. Hydrogen production is a seasonal business, and European partners rely on the capabilities of Ukrainian GSF to store a mixture or, in the future, pure hydrogen. Similar experiments and research have been carried out by the Austrian storage operator RAG Austria for more than 5 years. As a national company, Naftogaz considers its mission to launch the hydrogen market and increase competition.

Germany 2020 has adopted the H2 Global concept and created a fund of the same name with a capitaliza- tion of about EUR 2.8 billion. The fund is to promote the production of green hydrogen on an industrial scale in partner countries. Germany sees Ukraine as one of its partners on the European continent. In July 2021, H2 Global announced the launch of Ukraine's first tender for a 100 MW green hydrogen production project. To implement a 100 MW green hydrogen project, 300 MW of renewable electricity is required. The Lviv-based company Eco-Optima applied for this tender. Such hydrogen will cost about 6 euros per kilogram, while gray hydrogen at Ukrainian chemical plants sells for 2.75 euros. To produce green hydrogen, the company plans to use Siemens electrolyzers. The German concern manufactures such 28 megawatts electrolyzers. To implement a 100 MW green hydrogen production project, four such plants and 300 MW of electricity from renewable sources are needed. The company’s operating capacity is 160 MW, and 45 MW of the Oryvka wind farm [15]. Thus, it is still necessary to build green power plants for 95 MW of electricity to ensure the production process under this tender. “Eco-Optima has announced plans to build a 100 MW green hydrogen plant in the northeast- ern part of the region. It is planned to produce hydrogen in Western Ukraine and supply it to Germany via the Urengoy-Uzhhorod-Bratislava gas pipeline” [16].

Established in June 2020, Hydrogen of Ukraine bought a land plot in the southern part of the Odesa region near the city of Reni to build the plant. In parallel, the company negotiated with financial institutions to raise funds and develop project documentation. The construction of the plant and solar power plant has started in early 2022. Several sales routes are being considered: nearby factories, transportation to the EU by river transport on the Danube, and transportation through the GTS. A contract has also been agreed with the German company RAG Austria AG and Bayerngas GmbH for the supply of “green” hydrogen to Germany [17]. In general, it is still a loss-making project, so we need a subsidy at the state level to buy green hydrogen.

To estimate the cost of hydrogen, the main technical and economic indicators of the electrolysis process should be taken into account. To produce 1 kg of H2, an average of 55 kWh of electricity generated at RES power plants and 9 kg of H_2O are required. When 1 kg of H2 is used as an energy carrier, 33 kWh is released during combustion, i. e. the efficiency of the complete process (production-use) is approximately 60 %. For comparison, the efficiency of an internal combustion engine is within 33 %. This shows that the claims about the inefficiency of the "green" hydrogen-based process are unfounded. The production of electrolyzers makes it possible to create stations with hydrogen capacities ranging from 0.5 Nm^3/h to 210 Nm^3/h and more.

In Ukraine, a model of a 10 kW non-transmission wind turbine was tested following the established regulations at the Pogorelyi State Research and Testing Institution [2]. The justification of the combined wind-solar system balance for the energy supply of agricultural production allowed the issuing of recommendations approved by the Ministry of Agrarian Policy of Ukraine. At the same time, a tracker unit with automatic control of the azimuthhal and zenithal orientation of a solar power plant consisting of eight photovoltaic panels with a total capacity of up to 2.3 kW was developed and manufactured, permanently connected to the consumer power grid through a three-channel hybrid inverter [3]. In addition, there is a well-known solid plant-based thermal power production [4], in which electricity and heat are produced in a cogeneration unit with an ash cleaning and utilization system. However, the carbon-free technology of hydrogen production and its joint operation with wind and solar power plants have not been studied [8], [18, 19].

This problem becomes relevant with the development of the concept of "acceptable risk" [20, 21]. At the same time, the issue of scientific validity and ade- quacy of calculation methods is one of the key issues.

5 Calculation justification

The energy parameters of the geothermal energy factor studied in [16] are of industrial importance. An electric geothermal power plant is based on a single well isolated from reservoir fluids, which produces 8 MW of primary thermal energy into electricity of more than 5 MW. It also generates hydrogen with a capacity of more than 10 kg/h. The potential thermal capacity of the Geological Environment-Well-Air system is 50 % of the total thermal capacity and can reach more than 10 MW at a depth of about 4000 m.

One of the physical explanations for the significant density of heat fluxes at the depths of the Geological Environment (GE) is the volume density of infrared waves (IR), which for 100 °C of rocks, according to the Stefan-Boltzmann law, reaches 12 kW/m^2. The known average values of heat fluxes at the level of 50 mW/m^2 are the result of the absorption of IRW by rocks in a nar- row bandwidth. Fluids have a much wider range of IR scattering, which explains the existence of geothermally active zones in Ukraine, where all oil and gas deposits are located. That is, the temperature of the GE is a consequence of the absorption of IR by rocks and fluids. For example, for a geothermal gradient of 0.03 °C/m, the Stefan-Boltzmann law gives a heat flux density of 0.11 W/m^2 with a GE emissivity factor of 0.8, which is the same as the thermal conductivity of the GE of 3.69 W/m/°C (3.69 × 0.03 = 0.11 W/m^2).

The second physical explanation for the IR generation is the increase in the intensity of vibrations of GE atoms and molecules with a gradual increase in gravitational energy with depth, which changes the Debye temperature in the case of an increase in all-around compression. In this case, each GE point is a stable generator of thermal energy, which can be reduced only by reducing the geostatic bulk pressure [22].

In [23–25] are presented and proved the physical reflection of the "hot" Earth hypothesis about the nature of geothermal energy, the conversion of gravitational energy into thermal energy. The authors have developed a comprehensive mathematical justification for this representation based on known ground and remote sensing data for the development of geothermal resources, environmental monitoring, and forecasting of the thermodynamic state of the atmosphere. Values of geophysical characteristics indexes depending on well depth are specified in Table 1 [24].

This makes it possible to estimate the heat flux and the effect of heat transfer of the solid phase to its torch on the drill string tubing space structures. The characte- ristics of the main means of deep wells in Ukraine are given in Table 2.

6 Energy balance and quality indicators

The heat flux density of 398.2 W/m^2 from medium and long infrared waves corresponds to the average temperature of the Earth's surface, which, according to the Stefan-Boltzmann law, is 16.3 °C. At a depth of 50 m, where the typical temperature is 10 °C, exogenous and endogenous heat flows with opposite gradients are formed. Therefore, conductive cooling of the Earth at this depth has almost stopped. The Earth is in an adia- batic thermodynamic state. The temperature of the litho- sphere at a depth of 50 m remains unchanged at an ave- rage temperature of 10°C (283.15 K) with a correspond- ding heat flux density of 364.46 W/m^2.

The physical fact of the thermogradient in the GE as the main factor in the difference in the stationary thermoplastic states of rocks at the depth of their occurrence is explained in [26–28]. Additional anomalies are considered: different horizontal tectonic stresses and faults, different fluid saturation, physical and chemical transformations, the composition of rocks absorbing IR, the main heat flux of the core IR wave, and the proximity of magmatic particles. The accumulated gravitational energy per unit volume of rocks increases with depth, which leads to a mounting up of the temperature and volumetric modulus of elasticity. Or, the internal energy of rocks at each depth is in thermodynamic equilibrium with gravitational energy. The Stefan – Boltzmann law determines the temperature of rocks at each point in the vertical direction. The temperature of the rocks supposedly forms the heat transfer, which is determined by Fourier's law of heat conduction. This heat transfer is insignificant, and there is a fixation of different stationary thermodynamic states of rocks. This fact is confirmed by thermometry in deep wells when the drilling mud after a day's pumping is of a temperature of 130 °C at the bottom hole and 10 °C at the wellhead [29].

Table 1. Comparative of geophysical characteristics indexes depending on well depth

Geophysical characteristics, unit of measure	Mark	Value	Value	Value
Depth, *m*	z	50	1000	5000
Temperature, *K*	$T_3(z)$	288		
Pressure, *bar*	$P(z)$	25	200	300
P-wave propagation velocity at depth *z* in the GE, *km/s*	$Vp(z)$	1.6	1.6	5.8
S-wave propagation velocity at depth *z* in the GE, *km/s*	$Vs(z)$	0	0	3.2
The density of gravitational energy, *J*	*Eg-teor (p-var)*	6.95E + 05	2.23E + 12	7.06E +15
Actual minimum length of the acoustic wave in the Earth, *m*	Λ_{min}	4.99E − 10	4.99E − 10	1.50E − 09
Temperature Debye matter of the planet, *K*	$T_D(z)$	410.30	410.30	493.00
Coefficient of thermal conductivity, *W/m/°C*	$_{SB}$*_fact*	38.94	37.85	373.09
Coefficient of thermal conductivity, *W/m/°C*	$_f(z)$ *g-const*	2.68	2.68	80.40
The gradient of thermal conductivity, *K/m*	*grad (T)*	5.25E + 00	2.62E – 01	1.78E – 01
Coefficient of radiation absorption, *1/m*	a_R/n^2	1.29	1.33	1.33

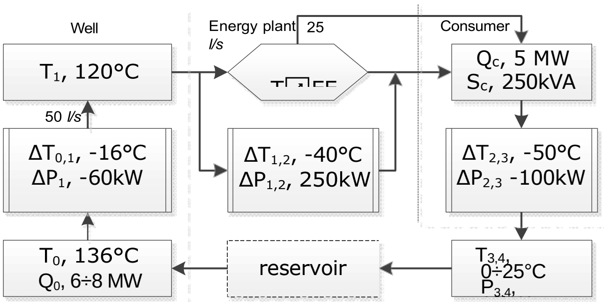
Table 2. Indexes of drilling mud circulation in the well

Well parameter	Markings	Value	Unit of measure
1	2	3	4
Bottom hole temperature	T_{gm}	106.3	°C
Depth of the artificial bottom hole	L_m	3975	m
Drilling mud density	ρ	1255	kg/m^3
Drilling mud temperature at the well entrance (flushing)	T_{in}	49.65	°C
Drilling mud temperature at the well outlet	T_{out}	50.12	°C
Drilling mud volume in the well	W_{pc}	137.83	m^3
Drilling mud velocity in the drill string tubing space	V_{dk}	4.482	m/s
Drilling mud velocity in the intertube space	V_{ok}	1.628	m/s
Weight of drilling mud in the well	M_{pc}	172.971	ton
Specific heat capacity of the drilling mud	C_p	3531.76	J/kg/K
Specific heat capacity of metal of containers and drill string	C_{Fe}	460	J/kg/K
Total time of drilling mud movement in the drill string space	t_2	878.5	s
Total time of drilling mud movement in the drill string washout space	t_1	2418.78	s
The average temperature gradient of the geological environment	γ_g	0.0264	°C/m
Performance of two drilling pumps	Q_{out}, Q_{in}	41.8	l/s
Power of drilling pumps (2 pcs.)	N_H	919.6	kW
Average temperature in the well before flushing	T_{gcp}	58.15	°C
Average temperature in the well during stationary flushing	T_{pm}	70	°C
Average atmospheric temperature near the Earth's surface	T_0	14.2	°C
Thermal power losses in the geological medium	$N_{\Delta g}(t, L < L_0)$	13.88	MW
Power losses from convection (15 W/ºC/m²)	$N_K(t, \Re_0)$	0.207	MW
Power loss from radiation	$N_{SB}(t, \Re_0)$	0.154	MW

Continuation of **Table 2**

1	2	3	4
Heat flux density	n	4817.7	W/m^2
The heat capacity of the geological medium is assumed	C_g	960	J/kg/K
Heat capacity of steel (Fe)	C_{Fe}	460	J/kg/K
Density of geological medium	θ_g	2600	kg/m^3
Density of steel	θ_{Fe}	7800	kg/m^3
Average density of heat flux of infrared waves on the surface of the lithosphere (depth of 50 m)	$\eta_{3\text{-SB}}$	364.46	W/m^2
Total power of conductive heating of the Earth	$N_{3\text{–}F}$	$4.44 \cdot 10^{13}$	W
Total power of internal source radiation	$N_{3\text{–SB}}$	$1.86 \cdot 10^{17}$	W
The total internal energy of the crust	E_K	$8.01 \cdot 10^{28}$	J
The total internal energy of the atmosphere	E_A	$1.64 \cdot 10^{29}$	J
Coefficient of heat transfer of solid phase to the atmosphere	A_K	$6.673 \cdot 10^{10}$	J/s/°S

An assessment of the feasibility and utility of accessing geothermal energy from the existing Jachowka K-2 production well was conducted [26]. A discussion of both the heat flux transferred between the sediment and the coolant as well as the heat flux passing through the barrier is presented. A computational model was developed to determine the volume of the resulting geothermal heat flow using a two-pipe geothermal heat exchanger with a dead point [27]. The results of calculations of the available heat flux in the studied well at a depth of L = 3950 m are analyzed.



Energy balance (geothermal-heat + electricity) of deep well energy plant

In the above examples of RES and hydrogen production, to assess the efficiency of the energy supply system, it is necessary to establish criteria and quality indicators for the following components:

– comparative structure and technological schemes of the poly-version system of renewable sources of decentralized generation and carbon-free hydrogen technologies

– calculated energy balance of the system;

– justification of the optimal ratio of installed generating capacities from each type of renewable source;

– management of the energy complex with optimized control parameters;

– production tests of the experimental poly-version system of renewable sources of decentralized energy supply and carbon-free hydrogen technologies [28].

Based on the obtained data, the concentration limits are calculated (Fig.).

Heat exchange in radiation is expected during drilling, the rest is convective heat transfer [29–31].

7. Conclusions

The compared performance of several studies of autonomous energy supply systems (biogas – heat + electricity, geothermal – heat + electricity, geothermal – heat + electricity + electrolyze hydrogen) included the energy efficiency indicators of two geothermal complexes for heat and power generation study. The efficiency of the geothermal system can reach up to 25 % of the calculated and experimentally obtained values. The main factor of efficiency is the availability and presence of decentralized energy supply system elements at the critical facility. An important component of the performance indicator is the efficiency of heat-electricity conversion.

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9. Conflict of Interest

The authors state that there are no financial or other potential conflicts regarding this work.

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