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The Functioning Concept of the Stabilization System of the Power Grids Operation in Terms of Supply Chain Phases in Operations Based on a Hydrogen Energy Buffer

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Abstract:

Purpose: *The aim of the research undertaken in the article is to present the concept of the functioning of the system of stabilization of the operation of power grids in terms of supply chain phases into activities based on the hydrogen energy buffer from the use of hydrogen.*
Design/Methodology/Approach: *There is a research gap in the world literature related to the project of the concept of stabilizing the operation of power grids. This article assumes that the main factor destabilizing the operation of power grids in the long term is the surplus of energy from RES (supply phase). There is no interdisciplinary approach to the presented issues, therefore the common area discussed in the article is of great scientific and application significance.*
Findings: *The current work on hydrogen technologies shows that the use of hydrogen in the economy adjusts the systems to its extraction, production and distribution. In this scope, there must be comprehensive design and management of processes in the phase of supply, production, storage and distribution of hydrogen, in terms of efficiency and maximum support for the achievement of socio-economic goals.*
Practical Implications: *Solving the problem related to the instability of renewable energy sources due to the dependence of the volume of energy produced on uncontrolled factors. In the near future, this problem will only increase due to the increase in the number of producers of electricity from RES and the instability of the operation of power grids. Therefore, it is important to prepare a concept for the operation of the power grid stabilization system in terms of the supply chain phases.*
Originality/Value: *The priority direction of political actions in the field of sustainable development of the energy sector is the course of the energy transformation (decarbonisation) and the flourishing share of renewable energy sources (RES) in the primary energy supply. It is an innovative research area, integrating both theoretical achievements in the field of hydrogen supply chains and the operation and development of power grids.*

Keywords: *Hydrogen, hydrogen energy buffer, renewable energy.*

JEL codes: *Q4, Q2, L7, O13.*
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1. Introduction

The contentment of the increasing demand for energy and the reduction of the importance of the energy sector for the environment and society are two interrelated embarrassments of the modern world (Lu *et al.,* 2020; Costantin and Crespi, 2013; Hnatyshyn, 2018). The pejorative effects of climate change are a significant challenge for the energy sector, which is vulnerable to political pressure to reduce greenhouse gas emissions, mainly carbon dioxide (Papadis and Tsatsaronis, 2020; Shindina *et al.*, 2018).

The priority focus of policy moves in the field of sustainable development of the energy sector is the course of the energy transition (decarbonisation) and the flourishing share of renewable energy sources (RES) in primary energy supply (Streimikiene, 2020; Stavytskyy *et al.*, 2018; European Commission The European Green Deal). RES technologies create an excellent opportunity to reduce greenhouse gas emissions (Štreimikienė, 2021; Tvaronavičienė *et al.,* 2018; Wach *et al.,* 2021; Pach-Gurgul and Ulbrych, 2019).

However, renewables are defined as unstable energy sources, from the aspect to the relationship with uncontrolled factors such as weather, affecting the amount of energy produced. The increasing participation of unstable RES in the energy mix has many consequences for the operation of power grids (Mańkowska *et al.*, 2021; Panwar *et al.,* 2011).

Stabilization system is understood in this context as balancing the supply and demand for electricity, taking into account the resulting transmission losses (Mariyakhan *et al.,* 2020; Wach *et al.,* 2021). The development of a system solution stabilizing the operation of distribution networks will enable effective management of electricity, increase the flexibility of the grid in terms of the possibility of connecting new producers of energy from renewable sources (RES), increase the safety and reliability of the network, as well as improve the quality parameters of the supplied electricity (Pach-Gurgul and Ulbrych, 2019; Tvaronavičienė *et al.,* 2018).

With the flourishing of groups of electricity generators conditioned on RES, the issue of unstable operation of power grids will increase, primarily in the area of distribution networks. As a consequence, more attention is paid to the issue of energy storage arranged with RES related to the stabilization of the electricity distribution network, although one of the methods is the flowering of hydrogen technologies based on pure hydrogen (the so-called green hydrogen) (Frankowska *et al.,* 2022). Green hydrogen can be valued in the process of decarbonisation of the

energy sector and over time become one of the priority energy carriers used in the European Union (Shindina *et al.*, 2018; Hnatyshyn, 2018).

The exploitation of hydrogen technologies in the stabilization of RES related to the operational safety of the electricity distribution network obliges a holistic approach as well as critical planning not contrary to the concept of the outlined hydrogen supply chain, which characterizes the phases of supply, production, storage and distribution of electricity (Streimikiene, 2020; Stavytskyy *et al.*, 2018).

Research work on hydrogen supply chains is still at an early stage of development. The aim of the research undertaken in the article is to present the concept of the functioning of the system of stabilization of the operation of power grids in terms of supply chain phases into activities based on the hydrogen energy buffer from the use of hydrogen.

The article is divided into three parts. The first part presents hydrogen as a prospective form of stabilization of the operation of power grids. The second part presents the Concepts of the functioning of the system of stabilization of the operation of power grids in terms of the phases of the supply chain in operations. The third part of the article presents conclusions related to the concept of a system stabilizing the operation of the electricity distribution network based on a hydrogen energy buffer.

2. Hydrogen as a Prospective Form of the System of Stabilization of the Operation of Power Grids

Increasing the use of renewable energy sources (RES) in the system of stabilization of the operation of power grids has become a challenge for power engineers and scientists around the world. Even if hybrid renewable power systems have attracted the attention of the sustainable energy market, optimal use of solar photovoltaic or wind power is difficult, especially in local power grids. This is due to their variable and discontinuous nature, resulting from dependence on meteorological conditions.

Therefore, stand-alone renewable energy sources cannot guarantee reliable power supply. A typical solution to this problem is the use of hydrogen as an energy storage. Hydrogen is considered the energy vector of the future, especially if it is produced from renewables (Frankowska and Rzeczycki, 2021; Hensel, 2020; Oyekale *et al.*, 2020).

Hydrogen is one of the most promising alternative energy carriers, which in nature does not occur freely. Like electricity, it is not a source of energy and is taken as a secondary form of energy that is produced from natural and biological resources. It was predicted that hydrogen would play a major role in the future scenario of energy sectors. Hydrogen, as the lightest element with a density of 0.0695 relative to air, is an odorless, tasteless and colorless gas (Ogumerem, 2018).

Hydrogen is a clean fuel with no toxic emissions and can be easily applied. Indeed, the energy efficiency of hydrogen is about 122 kJ/g, which is 2.75 times more than hydrocarbon fuels. Hydrogen utilization does not produce toxic gases or CO2 emissions, and the only product is water vapor (Won *et al.*, 2017; Dominković *et al.*, 2018).

Table 1. *Characteristics of hydrogen combustion and detonation.*

Density at STP (Kg/m 3)	0,084
Heat of evaporation (J/g)	445,6
Lower calorific value (KJ/g)	119,93
High calorific value (KJ/g)	141,8
Thermal conductivity at std. condition (mW/cm/K)	1,897
Diffusion coefficient in air at std. condition (cm 2 s)	0.61
Limitations on the ability to smoke in the air (vol %)	4,0–75
Explosion limits in air (vol %)	18,3–59
Oxygen index limitation (vol %)	5.0
Stoichiometric composition in air (vol.)	29,53
Minimum ignition energy in air (Mj)	0,02
Auto-ignition temperature (K)	858
Flame temperature in air (K)	2318
Maximum speed of combustion in the air at std. state (m/s)	3.46
The speed of detonation in the air at std. condition (km/s)	1,48–2,15
Explosion mass energy in relation to g TNT (g)	24,0
TNT-related explosion volume energy (m3) (STP)	

Source: *Balat and Kırtay, 2010, 7416-7426.*

The use of hydrogen in the energy system will meet with great interest as an energy policy issue (Acar and Dincer, 2019).

Assuming that the dominance of renewable and sustainable energy from renewable energy sources in the world's energy mix in the near future is inevitable, the development of hydrogen production from rich resources of renewable sources may be the best policy to achieve a clean environment. The low price of hydrogen production and the environmentally friendly way play a key role in the further development of the economy, including hydrogen (Hosseini and Wahid, 2016; Nikolaidis and Poullikkas, 2017).

Hydrogen produced from renewable sources such as biomass, geothermal, solar and wind energy is ideal for the gradual replacement of fossil fuels. The chemical conversion of energy sources such as coal and biomass gasification, as well as NG steam reforming with CCS is one of the available processes with a high potential to contribute to hydrogen production. In addition, the electrolysis of water by electricity from renewable resources has great potential for development in the production of hydrogen. Some hydrogen production processes, such as fermentation,

thermochemical water fission, biophotolysis, and photoelectrolysis, are suitable for small-scale use (Reuß *et al.*, 2017; Alazemi and Andrews, 2015).

Table 2. *Hydrogen production technology.*

Technology	Raw material	Efficiency
Steam reforming	Hydrocarbons	70-85%
Automatic thermal reforming	Hydrocarbons	60-75%
Biomass gasification	Biomass	35-50%
Electrolysis	H2O + current	50-70%
Photolysis	H2O + sunlight	0,5%
Thermochemical water splitting	H2O + heat	ON

Note: *Hydrogen purification is not included.*
Source: *Balat and Kırtay, 2010, 7416-7426.*

In wind power plants, hydrogen could be used as an indirect energy carrier. Excess electricity is stored in the form of hydrogen and can be converted back into electricity during periods of low wind potential or after grid overload has ceased. The development of solar and wind power generation equipment and the reduction of associated electricity prices improve economic competitiveness (Kim *et al.*, 2008).

3. The Concept of Functioning of the System of Stabilization of the Operation of Power Grids in Terms of Supply Chain Phases in Operations

The Data Envelopment Analysis (DEA) is a non-parametric comparative Renewable energy sources are referred to as unstable, due to the dependence of the volume of energy produced on uncontrollable factors such as weather, time of day, etc. With the increase in the number of producers of electricity from RES, the problem of instability of the operation of power grids will grow (Frankowska *et al.*, 2022).

The solution to this problem may be the hydrogen buffer that is the subject of research in this Article. The hydrogen buffer consists of the following element:

1. electrolyser converting electrical energy (RES) into hydrogen,
2. hydrogen storage,
3. a fuel cell that converts hydrogen into electricity,
4. maintenance-free control system.

The hydrogen buffer is therefore treated as a tool for stabilizing power grids, at the same time supporting the processes of energy transformation (decarbonization).

The concept of locating the energy buffer in distribution power grids, taking into account the objectives of the EU's hydrogen policy (implying the objectives of climate and energy policy). The purpose of introducing a hydrogen buffer into the

energy system (distribution power grid) is to stabilize the operation of the network through the current impact on:

- the coefficient of equalization of the network load curve on a daily scale;
- quality parameters of the supplied electricity such as: voltage stability, frequency fluctuations and harmonic level;
- limiting the energy loss coefficient defined as a percentage of energy generated by RES sources that is impossible to accumulate and irretrievably lost.

In the indicated approach, the stabilization of the system is understood as balancing the demand and supply of electricity, taking into account the resulting losses on its transmission (energy demand = energy supply – losses in energy flow).

Due to the complexity and interdisciplinarity of research issues, the assumptions of the proposed stabilization concept included a supply chain layout that made it possible to separate the phases of procurement, production and storage and distribution.

The concept of stabilizing the operation of power grids assumes that the main factor destabilizing the operation of power grids in the long term is the surplus of energy from RES (supply phase). In the event of a surplus, it is returned from the MV (medium voltage) line to the HV (high voltage) line (the surplus is reduced by energy losses occurring on the transmission). This is an unfavorable phenomenon, because in addition to destabilizing the operation of power grids, it may ultimately result, for example, in the need to incur significant investment outlays for the modernization of power lines (HV).

The task of the hydrogen buffer is to stabilize the operation of power grids by converting excess electricity into hydrogen (electrolyser), hydrogen storage (storage) and conversion of hydrogen into electricity (fuel cell), (production and storage phase). The energy stored in hydrogen will be used to meet future demand in the event of periodic shortages. In addition, as a hydrogen fuel (distribution phase), it can also be used for DSO utility purposes (e.g. refueling of a fleet of vehicles). The by-product of the electrolysis process is oxygen, the sale of which may in the future be a source of revenue for DSOs (additional economic benefits).

4. Discussion and Conclusions

The production and use of electricity is associated with greenhouse gas emissions, as well as environmental devastation, which is mainly caused by gas emissions from the combustion of fossil fuels, especially coal. Hence, one of the most serious global problems today is excessive CO2 emissions, which causes the phenomenon of the greenhouse effect.

For this reason, the most important issue has become the reduction of CO2 emissions, and thus stopping climate change in the atmosphere. This objective is a major challenge in for the global energy sector.

In order to reduce emissions, it is therefore necessary to search for and use highly efficient economically efficient energy sources, since electricity is consumed at the same time as it is produced. At the same time, the places of production of electricity are usually located far away from the places where it is consumed.

At the moment, in the Polish energy sector, associated with the monoculture of coal, there is a lack of power, and the entire energy transmission system is beginning to resemble an open-air museum. The solution may be the concept of functioning of the system of stabilization of the operation of power grids in terms of supply chain phases in operations based on a hydrogen energy buffer from the use of hydrogen. It is an innovative research area that consolidates theoretical achievements in the field of hydrogen supply chains and the operation and development of power grids.

Previous research on hydrogen technologies shows that the use of hydrogen in the economy forces the adaptation of systems for its acquisition, production and distribution. In this area, it is necessary to comprehensively design and manage the processes carried out in the phase of supply, production, storage and distribution of hydrogen so that they are efficient and how optimally support the achievement of socio-economic objectives.

The results of the conducted research fill the existing research gap. First of all, there is no interdisciplinary approach to the issues presented. Secondly, the recommended common area is of great scientific and application importance.

References:

Acar, C., Dincer, I. 2019. Review and evaluation of hydrogen production options for a better environment. J. Clean. Prod., 218, 835-849.

Alazemi, J., Andrews, J. 2015. Hydrogen refuelling stations in the automotive industry: an international review. Refurbish. Sustain. Energy Rev., 48, 483-499.

Costantini, V., Crespi, F. 2013. Public policy for a sustainable energy sector: regulation, diversity and support for innovation. J. Evol. Econ., 23, 401-429.

Dominković, D.F., Bačeković, I., Pedersen, A.S., Krajačić, G. 2018. The future of transport in sustainable energy systems: opportunities and barriers in the clean energy transition. Refurbish. Sustain. Energy Rev., 82, 1823-1838.

European Commission European Green Deal. Striving to be the first climate-neutral continent. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

Frankowska, M., Rzeczycki, A. 2021. Hydrogen Supply Chains – New Perspective for Stabilizing Power Grid. Int. J. Latest Res. Eng. Technol. Available: https://www.academia.edu/44890883/Hydrogen_Supply_Chains_New_Perspective_for_Stabiliz ing_Power_Grid.

Frankowska, M., Błoński, K., Mańkowska, M., Rzeczycki, A. 2022. Research on the Concept of Hydrogen Supply Chains and Power Grids Powered by Renewable Energy Sources: A Scoping Review with the Use of Text Mining. Energies, 15, 866. https://doi.org/10.3390/ en15030866.

Frankowska, M., Mańkowska, M., Rabe, M., Rzeczycki, A., Szaruga, E. 2022. Structural Model of Power Grid Stabilization in the Green Hydrogen Supply Chain System-Conceptual Assumptions. Energies, 15, 664. https://doi.org/10.3390/en15020664.

Hensel, P. 2020. A Systematic Review of the Literature in Management and Quality Sciences. Syst. Review of the Lit. in the Sciences: Management and Quality Sciences. doi: 10.7172/978-83-66282-19-3.2020.WWZ.2.

Hnatyshyn, M. 2018. Analysis of the distribution of the impact of economic growth on emissions of ammonia and nitrogen oxides in the European Union. Journal of International Studies, 11(1), 201-209. doi:10.14254/2071-8330.2018/11-1/15.

Hosseini, S.E., Wahid, M.A. 2016. Hydrogen production from renewable and sustainable energy resources: A promising green energy carrier for clean development. Refurbish. Sustain. Energy Rev., 57, 850-866.

Kim, J., Lee, Y., Moon, I. 2008. Optimization of the hydrogen supply chain in conditions of demand uncertainty. Int. J. Hydrogen Energy, 33, 4715-4729.

Lu, Y., Khan, Z.A., Alvarez-Alvarado, M.A., Zhang, Y., Huang, Z., Imran, M. 2020. A Critical Review of Sustainable Energy Policy for the Promotion of Renewable Energy Sources. Sustain, 12, 5078.

Mańkowska, M., Pluciński, M., Kotowska, I. 2021. Marine biomass supply chains and secondary ports in the era of decarbonization. Energie, 14, 1796.

Mariyakhan, K., Mohamued, E.A., Asif Khan, M., Popp, J., Oláh, J. 2020. Does the level of absorption capacity matter for the intensity of carbon dioxide emissions? Evidence from the US and China. Energies, 13(2), 407, 1-19. https://doi.org/10.3390/en13020407.

Nikolaidis, P., Poullikkas, A. 2017. A comparative overview of hydrogen production processes. Refurbish. Sustain. Energy Rev., 67, 597-611.

Ogumerem, G.S., Kim, C., Kesisoglou, I., Diangelakis, N.A., Pistikopoulos, E.N. 2018. Multi-purpose optimization of the design and operation of the hydrogen network for transport fuel. Chem. Eng. Res. Des., 131, 279-292.

Oyekale, J., Petrollese, M., Tola, V., Cau, G. 2020. Impact of renewables on the efficiency of grid-integrated systems: a concise overview of current challenges and potential solution strategies. Energies, 13.

Pach-Gurgul, A., Ulbrych, M. 2019. Progress of the V4 countries in achieving the EU's energy and climate goals in the context of improving energy security. Entrepreneurial Business and Economics Review, 7(2), 175-197. doi.org/10.15678/EBER.2019.070210.

Panwar, N.L., Kaushik, S.C., Kothari, S. 2011. The role of renewable energy sources in environmental protection: an overview. Refurbish. Sustain. Energy Rev., 15, 1513-1524.

Papadis, E., Tsatsaronis, G. 2020. Challenges in the decarbonisation of the energy sector. Energy, 205, 118025.

Reuß, M., Thick, T., Robinius, M., Preuster, P., Wasserscheid, P., Stolten, D. 2017. Seasonal storage and alternative carriers: a flexible model of the hydrogen supply chain. Appl. Energy, 200, 290-302.

Shindina, T., Streimikis, J., Sukhareva, Y., Nawrot, Ł. 2018. Social and economic characteristics of energy markets. Economics and Sociology, 11(2), 334-344. doi:10.14254/2071-789X.2018/11-2/23.

Stavytskyy, A., Kharlamova, G., Giedraitis, V., Šumskis, V. 2018. Estimation of the interconnectedness between energy security and macroeconomic factors in European countries. Journal of International Studies, 11(3), 217-238. doi:10.14254/2071-8330.2018/11-3/18.

Streimikiene, D. 2020. Ranking of the Baltic States on progress in achieving the main objectives of energy security of the European Energy Union strategy. Journal of International Studies, 13(4), 24-37. doi:10.14254/2071-8330.2020/13-4/2.

Štreimikienė, D. 2021. Externalities of energy generation in the Visegrad Group countries and their integration through support for renewable energy sources. Economics and Sociology, 14(1), 89-102. doi:10.14254/2071-789X.2021/14-1/6.

Tvaronavičienė, M., Prakapienė, D., Garškaitė-Milvydienė, K., Prakapas, R., Nawrot, Ł. 2018. Energy efficiency in the long term in selected European countries. Economics and Sociology, 11(1), 245-254. doi:10.14254/2071- 789X.2018/11-1/16.

Wach, K., Głodowska, A., Maciejewski, M., Sieja, M. 2021. Processes of Europeanization of eu energy policy in the Visegrad Group countries in the years 2005-2018. Energie, 14(7), 1802. doi.org/10.3390/en14071802.

Won, W., Kwon, H., Han, J.H., Kim, J. 2017. Design and operation of a hydrogen supply system based on renewable energy sources: integration and optimization of technology. Refurbish. Energy, 103, 226-238.