COMPETITIVENESS OF POWER SYSTEMS WITH NUCLEAR POWER PLANTS AND WITH HIGH PARTICIPATION OF INTERMITTENT RENEWABLE ENERGY SOURCES

by

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In the paper are presented and discussed the results of a more complex research of technology portfolio's competitiveness in power systems with high penetration of intermittent renewable energy sources (i-RES). Possible technology portfolios compositions are analyzed. The portfolios comprise very high participation of i-RES, as well as a certain participation of energy storage technologies, but also and other energy technologies like nuclear and fossil fueled power plants. Within the research are developed new competitiveness indicators i.e., dispatchability indicator and the technology portfolio's assured capacity. The latter is defined on the basis of recently published Ulrich's and Schiffer's paper. Obtained results point out that inclusion of pumped-hydro storage plants improves portfolio's dispatchability. However, within the researched interval up to PHS installed capacities relative to i-RES capacities of 0.3. Numerical values of the dispatchability indicators are still below their values for the portfolio without i-RES. Increased participation of nuclear power plants contribute to the improvement of numerical values of the dispatchability indicators. The sensitivity analysis for the case of two times smaller cost of pumped hydro storage capacities is also performed. Hypothetical change of power system's technology structure in sense of substitution hard coal and lignite fired power plants with wind generators or with nuclear power plants is also analyzed. The analysis points out that the substitution with nuclear power plants enables much better results regarding power system's ability to change the power on demand than substitution with wind generators, particularly in the countries with high participation of hard coal and/or lignite in electricity generation.

Key words: *dispatchability indicators, energy technology portfolios, nuclear power, pumped-hydro storage, competitiveness*

Introduction

Having in mind Porter's concept of competitiveness [1], Krugman's critic of that concept [2], as well as Chorafas's approach to environment and natural resources competitiveness [3], in this paper competitiveness is considered as capability of an energy technology to compete other energy technologies, as well as capability of an energy technology portfolio to compete other energy technology portfolios. It is assumed that capability of an energy technology, or an energy technology portfolio to compete others is closely related to their abilities to satisfy social request of the higher order to reduce CO_2 emission, as well as the power systems internal

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request to change the power on demand. Competitiveness of an energy technology is determined in accordance with its individual contribution to overall technology portfolio's competitiveness.

In previous research [4, 5], was investigated participation of nuclear power plants (NPP), as well as i-RES in electricity generation of a referent power system on the systems competitiveness. The research pointed out that there are two intervals of i-RES participation in a power system's overall load domain. In the first one, with increasing participation of i-RES from zero value, competitiveness of the power system decreases reaching its the lowest value at about 40% of i-RES participation. In the second one, with increasing i-RES participation over about 40%, competitiveness of the power system increases. In both intervals, increase in participation of NPP in residual load domain* contributes to the power system's competitiveness. The question can be put whether aforementioned results are enough for bringing final conclusions in the case of power systems with high penetration of i-RES? Do we need, in these cases, a wider approach that includes better tailored technology portfolio for electricity generation and in addition appropriate defined indicators as well? These questions are grounded on the perception that great penetration of intermittent sources needs to be investigated and regarding power system's ability to change the power on demand *i.e.*, that a more complex analysis is necessary. In the case that the power system is not dispatchable at the satisfactory level, it must buy, or sell, the electricity abroad. Such trading activities under *pressure of must* are the most probably connected with significant financial losses, as is already indicated in literature [6].

The motivations for the present research are to investigate more in detailed competitiveness of the power systems with high participation of i-RES, as well as to encompass the influence of the power system's ability to change the power on demand on the power system's competitiveness.

Indicators for competitiveness assessment

In [7] was developed and presented, among others, and 3*E* indicator. This indicator was used for evaluation of power systems technology portfolio's competitiveness regarding investments in assets, CO_2 emission and electricity generated. The corresponding results were presented in [8, 9]. The intention was to include environment requirements in the field of competitiveness. As explained in [7] the 3*E* indicator is expressed in analytically form:

$$3E = \frac{\sum_{i=1}^{n} f_{cESi} \sum_{i=1}^{n} m_{\mathrm{CO_2}\,ESi}}{\sum_{i=1}^{n} e_{ESi}} \tag{1}$$

where f_{cESi} denotes annual amount of fix cost (expressed in millions of euro per year) for i^{th} electricity source, $m_{\mathrm{CO_2}ESi}$ denotes annual amount of CO_2 emission (in thousand tons per year) of i^{th} electricity source, e_{ESi} electricity generation (in MWh per year) of i^{th} source, while n is the number of all electricity generating sources. The competitiveness of the considered portfolio for electricity generation is as better as is lower value of 3*E* indicator.

For a power system with high penetration of i-RES, it appears that 3*E* indicator, taken alone, is insufficient for making proper estimate of the power system's competitiveness. Therefore, addition indicators have to be introduced. Dispatchability of a power system describes capability of the power system to response on demand to change the power [10]. In order to

* Residual load domain is the part of the annual load diagram that remains after subtraction of the electricity generated by i-RES, as is explained in literature [4, 5]

be able to change the power on demand a power system must have enough power on disposal in the time the demand is set. At this point we are setting a reasonable assumption that the *pressure of must* in electricity selling/buying activities of a power system is as lower as higher is dispatchability level of the power system. Then, it follows that more competitive is power system with greater dispatchability. Based on this consideration, the technology portfolio's dispatchability indicator can be defined:

$$DI = \frac{\sum_{i=1}^{n}\left[\left(1-\frac{P_{ti\min}}{P_{ti\mathrm{nom}}}\right)P_{ti\mathrm{nom}}\right]}{\sum_{i=1}^{n}P_{ti\mathrm{nom}}} = \frac{\sum_{i=1}^{n}\left[DF_{ti}P_{ti\mathrm{nom}}\right]}{\sum_{i=1}^{n}P_{ti\mathrm{nom}}} \tag{2}$$

where $P_{t\,i\,\min}$ [MW] is the minimal operable power of i^{th} electricity source, $P_{ti\mathrm{nom}}$ [MW] – the nominal power of i^{th} electricity source, while n denotes the number of all electricity generating sources. Value in round brackets, expressed as $DF_{t\,i}$, is named as dispatchability factor, which represents a technological feature of each source. In application of previous equation arises a practical problem of determining the dispatchability factor for each individual plant, since its numerical value differ not only for different technologies, but often also and for different plants' types within the same technology group. In principle, dispatchability factor can be improved by applying adequate design or refurbishment measures. Some examples are presented in [11, 12].

Recently, Ulrich and Schiffer [13] introduced assured capacity as the indicator for electrical power plants. Their definition of assured capacity in sense corresponds with definition of capacity credit given by Furch *et al*. [14], for i-RES technologies. Besides, Ulrich and Schiffer [13] provided the values of assured capacity for each power generation technology in the German conditions. An approach in defining appropriate indicator on the technology portfolio's level is given in [15].

Based on the data presented by Ulrich and Schiffer [13], and in accordance with the approach given in [15], an indicator that indicate assured capacity at the level of the power system's technology portfolio can be defined:

$$ACT_{PS} = \sum_{i=1}^{n}\left(AC_i\frac{IC_i}{\sum_{i=1}^{n}IC_i}\right) \tag{3}$$

where with AC_i [%] is denoted assured capacity at the power plant's level according to Ulrich and Schiffer [13], while with IC_i [MW] is denoted installed capacity of the considered technology (*i.e.*, all power plants) in the considered power system. Aforementioned equation is valid under the assumption that the value in brackets has the additive nature.

In the current research the goal is to include into the competitiveness analysis the inter-dependance of the power system's technology structure and the dispatchability capability of the system. For the systems with i-RES, it was shown convenient to define the power system's technology structure with two indicators. First represents the ratio of the annual amount of electricity generated by i-RES technologies and the total electricity produced by all technologies in the system, λ, while the second one represents participation of NPP in the residual load domain of the considered power system, β, as was earlier exemplified in [4, 5]. For the subject analyses third necessary indicator is defined as the ratio of the installed pumped-hydro storage (PHS) plant's power to the installed power of all i-RES capacities in the considered power system. In the wording ahead this indicator is referred as storage capacity power ratio (SCPR).

Energy technologies and technology portfolios

We can classify all dispatchable technologies as those with zero emission of CO_2 (hydro power, nuclear power, biomass fired, wind generators – WG, photovoltaic), technologies with relatively high emission of CO_2 (like fossil fueled technologies) and technologies with limited emission of CO_2 – that represent the combination of fossil fueled and carbon capture and storage (CCS) technologies. On the other hand, we can classify all CO_2 free technologies as dispatchable ones (hydro power, nuclear power and biomass fired), as non-dispatchable ones, like WG, photovoltaic and solar thermal technologies, as well as limited dispatchable technologies that represent the combination of some of non-dispatchable technology and appropriate electricity storage (ES) technology. Previous classification, together with the technology matrix presented in [9], leads to definition of extended technology matrix, which is developed and discussed in [16]. In the concept of extended technology matrix important roll play technologies for CCS as well as technologies for ES. Competitiveness of fossil power plants combined with CCS was examined in previous research [4, 5, 7-9].

A wide number of ES technologies is analyzed in modern literature [17-19]. However, only three of them are commercially available with recognized cost. These are: compressed air electricity storage (CAES), PHS, and batteries.

Batteries for ES are in an intensive development [20], since this technology has great flexibility in selecting the location for installation. Data published in [21] exemplifies the powers of 15 MW that can be reached at the certain location. On the other hand, both CAES and PHS need appropriate location for installation. Hydro power storage plants are widely used around the world and thy are reaching great installed powers. Therefore, this technology in combination with WG is selected to be a part of the technology portfolio in further competitiveness analysis.

Analysis and results

The analyses are based on the power system's load duration curve that is more or less typical for the European conditions. The curve is previously explained in references [4, 5, 7-9]. The technology composition of the power system is as follows. Wind turbines with priority in-feed are foreseen as the representative of i-RES technologies. For improving system's dispatchability characteristics are foreseen PHS power plants that store and in-feed into system the electricity generated by the i-RES. In the basic part of the residual load domain are foreseen lignite fired (LfPP) and NPP, in the intermediate part are foreseen hard coal fired power plants (HCfPP), while in the pick part are foreseen combined cycle gas turbines (CCGT).

For the analyses is used analytical model described in [22] with necessary adoptions for the case. Energy characteristics of the considered technologies, used in the analysis are the same as was used in [4], see also tab. 1. Dispatchability factor DF_t is estimated on the basis of our own experience as more or less average value for the running plants within each considered technology. Wind turbines and PHS are considered as one entity and for this entity DF_t is equal to the current value of the SCPR. Asset's costs that are used in the analysis correspond to prices in 2016, according to [23, 24]. Cost of wind turbines is 2083 € per kW and correspond to the costs in 2016. Cost of the PHS power plant is varying within wide interval, depending to the local orographic conditions, capacity of energy storage and installed power [25]. In our analysis we used cost of 1800 € per kW. This figure is in the upper part of the cost interval given in

[25], but not the highest one. The average values of CO_2 generation per unit of fuel energy for different fuels are calculated using data from reference [26].

Table 1. Technology characteristics and costs of the considered technologies, [4, 23, 24]

Technology	LfPP	HCfPP	CCGT	NPP
Efficiencies [%]	42	43	60	33
DF_t [–]	0,5	0,5	0,55	0,6
Costs [€ per kW]	3515	3056	963	5206

The analyses were performed numerically with the indicators λ and β that indicate the configuration of the considered technology portfolio as independent variables and with indicator SCPR, as known parameter.

In fig. 1 are presented calculated values of the dispatchability indicator for the typical European power systems load conditions. In the case of technology portfolio without pump-hydro storage plants and without NPP, an increase in participation of i-RES from zero value to very high value* of about 60%, results in significant decrease of the dispatchability indicator for almost three times. Inclusion of pump-hydro storage plants with installed capacities relative to i-RES capacities of 0.3 in the considered technology portfolio, results in nearly doubled value of the dispatchability indicator. This presumes in the same ratio better possibilities of the power system to respond on demand to change the power. However, even this increased value of the dispatchability indicator amounts only about 70% of its value for the technology portfolio with zero participation of i-RES without pump-hydro storage plants and without NPP.

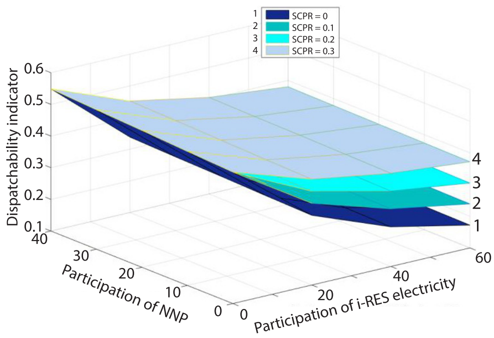

Figure 1. Dispatchability indicator as function of β and λ indicators

Calculated values of the technology portfolio's assured capacity (at the level of entire power system) are presented in fig. 2. General shape of resultant surfaces is similar to those of the previous dispatchability indicator, but somewhat less steep. Also, inclusion of pump-hydro storage plants gives smaller increase in numerical value of the power system's assured capacity, that in the case of 60% i-RES participation, with pumped-hydro plants capacity relative to i-RES capacity of 0,3 and without NPP is about 1.7 times greater than in the case of the portfolio with 60% i-RES participation, without PHS capacities and without NPP.

In fig. 3 are presented calculated values of the $3E$ indicator. Nota bene competitiveness of the power system is as better as is lower value of $3E$ indicator. Inclusion of pump-hydro storage plants in the considered technology portfolio, results in an increase of $3E$ indicator *i.e.*, in corresponding reduction in the power system's competitiveness.

* Five levels of i-RES participation are assumed *i.e.*, low $\lambda < 20\%$, medium $20 < \lambda < 40\%$, high $40 < \lambda < 60\%$, very high $60 < \lambda < 80\%$ and extra high $\lambda > 80\%$

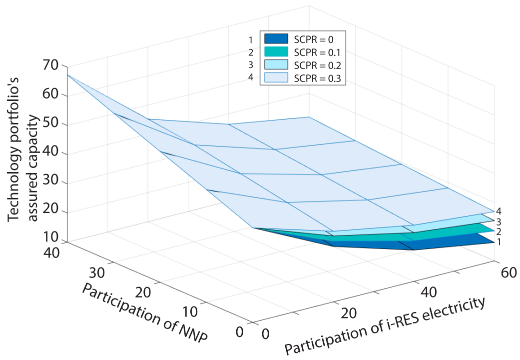

Figure 2. Technology portfolio's assured capacity (at the power system's level) as function of β and λ indicators

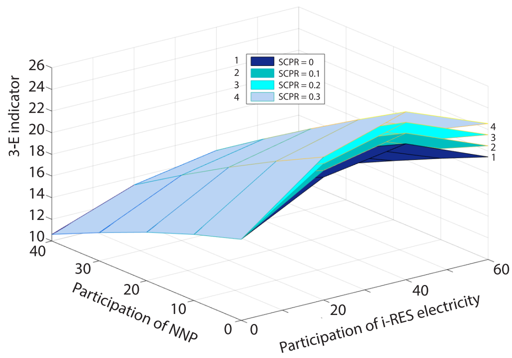

Figure 3. The 3*E* Indicator as function of β and λ indicators

On the other hand, adding NPP into technology portfolio enables reduction in 3*E* Indicator's numerical value and, thus competitiveness improvement of the considered power system.

Existing technology portfolios

Previous analysis is further extended to the existing technology portfolios in selected nine European states. Eight of them are EU member states and one is not. Six states have NPP in operation, while the other three have not. For the calculations are used data from tab. 1. Data for installed capacities for different technologies, as well as the electricity generation are taken from references [27-34] and are valid for the year 2015. Only for Serbia installed capacities, mainly for wind turbines, photovoltaic and biomass capacities and electricity generation correspond to the year 2019, according to [35, 36].

In fig. 4 are presented calculated values of dispatchability indicator in co-ordinate system β-λ with printed calculated values of SCPR for these nine states. It can be recognized that the states with greater participation of i-RES in electricity generation have lower values of dispatchability indicator. Similarly, the states with greater participation of i-RES in electricity generation have lower values of the technology portfolio's assured capacity, which can be seen in fig. 5. On the other hand, the states with greater participation of NPP in electricity generation have in principle higher values of the portfolio's assured capacity.

Discussion

With an increase participation of i-RES in electricity generation, decrease continually numerical values of dispatchability indicator and technology portfolio's assured capacity, and thus decreases the power system's competitiveness in that respect. For the technology portfolio with 60% participation of i-RES without PHS and zero participation of NPP, numerical values of these indicators reach considerably small values *i.e.*, smaller about 3 times and 2.6 times, respectively, than in the case of portfolio with zero participation of i-RES, without PHS and without NPP. Additional inclusion of PHS power plants in the technology portfolio enable improvement of the power systems capability to change the power on demand. However, in the largest considered installed PHS capacity relative to i-RES capacity of 0.3 with i-RES participation of 60% and without NPP, numerical values of these two indicators are about 28%, respectively, 37% lower than the corresponding values in the case of portfolio with zero participation of i-RES, zero participation of PHS and zero participation of NPP.

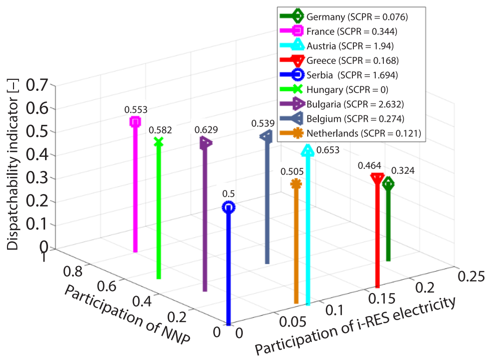

Figure 4. Dispatchability indicator as function of β and λ indicators for selected group of nine European states

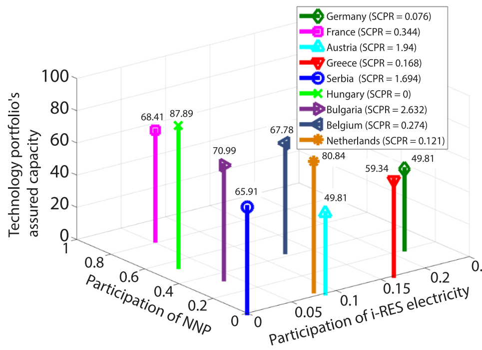

Figure 5. Technology portfolio's assured capacity for the power system as function of β and λ indicators for selected group of nine European states

In general case, whether an increase in participation of NPP in residual load domain produce an increase or a decrease of the dispatchability indicator, depends to the ratio of actual values of power factors for applied nuclear and fossil fueled power plants. In our case power system with 20% participation of NPP and zero participation of i-RES and zero participation of PHS, has about 40% better value of the dispatchability indicator than the power system with 60% participation of i-RES with PHS relative capacity of 0.3 and zero participation of NPP. Thereby numerical value of the technology portfolio's assured capacity indicator becomes about doubled.

Inclusion of PHS power plants in the technology portfolio has as a consequence greater numerical value of 3*E* indicator, see fig. 3, and thus smaller competitiveness level in that respect.

The sensitivity analyses point out that in the case of 50% smaller investment cost for PHS technology *i.e.*, of 900 € per kW, the power system with 60% participation of i-RES with PHS relative capacity of 0.3 and zero participation of nuclear power plants still has about 20% greater numerical value of 3*E* indicator *i.e.*, smaller competitiveness level, related to the power system with zero participation of i-RES without PHS and without NPP. Power system with 60% participation of i-RES with PHS relative capacity of 0.3 and 20% participation of NPP (in residual load) has even slightly improved (about 5%) competitiveness in regard to the power system with zero participation of i-RES without PHS and zero participation of NPP.

There are ongoing discussions, mainly in some EU countries, about drastic changes in technology structure of the portfolios for electricity generation in sense of hard coal and lignite fired power plants (LfPP) phase out. Target is further and significant reduction of CO_2 emission. There are many sever consequences of such a change in technology structure. One of them is drastic reduction of the power systems ability to change the power on demand.

In order to investigate this problem three portfolios structures are considered for each of nine selected European countries. First one is the basic structure, which is the same as those from figs. 4 and 5. Second one is the hypothetical structure obtained when all hard coal and LfPP are substituted with wind turbines. Third one is also the hypothetical structure obtained when all hard coal and LfPP are substituted with NPP. There are no other addition changes in the portfolio's structures. For each of so defined technology portfolio's structures are calculated numerical values of dispatchability indicator and the technology portfolio's assured capacity.

In order to maintain the same electricity generation in all considered technology structures, wind turbine capacities are calculated on the basis of 3500 hour per year equivalent number of operation hours at full load for off-shore capacities (for Germany), and 2500 hour per year for on-shore capacities (for all other countries). Analogues, NPP capacities are calculated on the basis of 8000 hour per year equivalent number of operation hours for all the countries.

The calculation results are presented in figs. 6 and 7. The two groups of countries can be recognized. First group compresses countries with relatively low participation of hard coal and LfPP in electricity generation, like France, Austria, and Belgium. In these countries, substitution of hard coal and LfPP either with wind turbines or with NPP does not cause great changes in numerical values neither of dispatchability indicator, nor of portfolio's assured capacity. Second group compresses countries with relatively high participation of hard coal and/or LfPP in electricity generation, like Germany, Greece, Serbia, and Bulgaria. In these countries the substitution of hard coal and LfPP with wind turbines causes great changes in numerical values of both considered indicators. Among countries in this group Serbia has the most drastic reduction of both indicators, *i.e.*, dispatchability indicator is about four times smaller, while portfolio's assured capacity is just over six times smaller compared to their values in the basic technology portfolio structure.

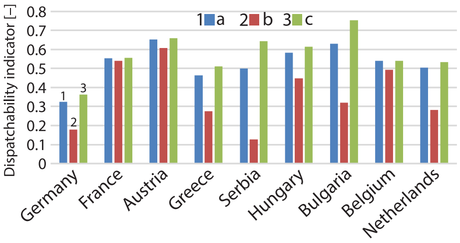

Figure 6. Dispatchability indicator for three portfolio's technology structures; (a) base; (b) HCfPP and LfPP substituted with WG, and (c) HCfPP and LfPP substituted with NPP

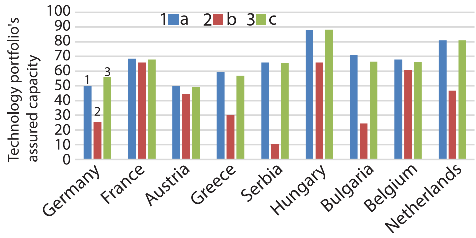

Figure 7. Technology portfolio's assured capacity for three portfolio's technology structures; (a) base, (b) HCfPP and LfPP substituted with WG, and (c) HCfPP and LfPP substituted with NPP

Beside reduced power system's ability to change the power on demand there are other negative consequences of hard coal and LfPP substitution with WG in the second group of countries. Some of them are discussed in reference [16].

On the other hand, substitution of hard coal and LfPP with NPP does not cause any significant reduction neither of dispatchability indicator, nor of portfolio's assured capacity in any of the nine selected European countries.

Conclusions

The extent to which the power system satisfies the social request of the higher order for reducing CO_2 emissions, as well as the system's internal technological requirement to change the power on demand are considered as the measure of the power system's competitiveness. The extent to which the power system can satisfy these requirements strongly depends on the technology structure of the systems technology portfolio. In the performed analyses are used three indicators for indication the technology portfolio's structure *i.e.*, indicators β, λ and SCPR, with special attention the regions with $\lambda > 40\%$, and $\beta < 40\%$. For quantifying the extent to which the power system satisfies aforementioned requests are used dispatchability indicator, power system's assured capacity and 3*E* indicator. First two indicators are used to indicate the power system's capability to change the power on demand, while third one is used for joint indication of investment costs for the assets, CO_2 emission and electricity generated. For improving competitiveness of a power system in regard to fulfillment aforementioned requests, there are available the options for technology portfolio's structure. The most promising options are analyzed and the results are presented and discussed.

Inclusion of PHS technologies results in corresponding improvement of power system's capability to change the power on demand. This fact is especially important in the case of portfolios with high participation of i-RES (40% and higher). However, such solutions reduce significantly power system's competitiveness regarding overall investment.

On the other hand, inclusion of NPP into technology portfolio for electricity generation enable improvement of the power system's competitiveness regarding the both requests.

In the hypothetical case of substituting hard coal and LfPP with CO_2 free technologies, the analysis points out that substitution with NPP enables much better results regarding power system's ability to change the power on demand than the substitution with wind turbines. This conclusion is particularly important for the countries like Serbia with high participation of hard coal and/or LfPP in electricity generation.

Nomenclature

ES – electricity storage
i-RES – intermittent renewable energy sources
CAES – compressed air electricity storage
CCGT – combined cycle gas turbines
CCS – carbon capture and storage
DF_t – dispatchability factor
HCfPP – hard coal fired power plant
LfPP – lignite fired power plant
NPP – nuclear power plant
PHS – pump hydro storage (power plant)
SCPR – storage capacity power ratio, [–]
WG – wind generators

Greek symbols

β – participation of nuclear power plants in the residual load domain, [kWh per kWh_{res}]
λ – participation of CO_2 free, non-dispatchable technologies (like wind turbines and photovoltaic) in total load domain, [kWh per kWh_{tot}]

References

[1] Porter, M. E., *Competitive Strategy: Techniques for Analyzing Industries and Companies*, Free Press, New York, USA, 1980
[2] Krugman, P., Competitiveness Dangerous Obsession, *Foreign Affairs*, *73* (1994), 2, pp 28-44
[3] Chorafas, D., Energy, Environment, Natural Resources and Business Competitiveness, GOWER, Surrey, England, 2011
[4] Grković, V., Doder, Dj., A Contribution Evaluation of Nuclear Power Plants Competitiveness Using 3E Indicator One Possible Approach, *Thermal Science*, *23* (2019) 6, pp. 4095-4105
[5] Grković, V., Doder, Dj., On Competitiveness of Nuclear Power Plants in the Concept of Sustainable Development with Strong Restrictions of CO_2 Emissions, *Proceedings*, (Eds. P. Stefanvić, D. Cvetinović), Power Plants 2018, Zlatibor, Srbija, 2018, ISBN 978-86-7877-029-6, pp. 351-361
[6] Stevanović, V., Challenges of Energy Transition in Germany – Successes and Failures, *Proceedings*, IEEP 2019, Zlatibor, Srbija, 2019
[7] Grković, V., Key Indicators for Competitiveness Assessment of Energy Technologies, *Proceedings*, International Conference Energy and Ecology Industry, Belgrade, Serbia, 2018, pp. 74-81
[8] Grković, V., Ecology, Economy and Energy Evaluation of Electricity Generating Technologies Using 3E Indicator, Keynote Speech, *Proceedings*, (ed. G. Chen), IWEG2018, Hangzhou, China, 2018, pp. 139-144
[9] Grković, V., Evaluation of Electricity Generating System's Technology Mix Using 3E Indicator, *Journal of Thermal Science*, *28* (2019), 2, pp. 218-224
[10] Grković, V., Doder, Dj., At the Technology Level Settled Indicators for Energy Technologies Competitiveness Assessment, *Proceedings*, 19th International Conference on Thermal Science and Engineering of Serbia, SIMTERM 2019, Sokobanja, Serbia, 2019, pp. 848-857

[11] Jesche, R., *et al*., Flexibility through Highly-Efficient Technology, *VGB PowerTech*, (2012), 5, pp. 64-68
[12] Kahlert, J., *et al.*, Possibilities and Limits for Optimizing Operational Flexibility in Existing Power Plants, (in German), *VGB PowerTech*, (2013), 1/2, pp. 59-63
[13] Ulrich, S., Schiffer, H.-W., Prospects for Development of Power Generation in Europe, *VGB PowerTech*, (2019), 12, pp. 43-50
[14] Furch M., *et al*., Optimization of Power Plant Investments under Uncertain Renewable Energy Development Paths – A Multistage Stochastic Programming Approach, EWI Working Paper, No. 12/08, 2012
[15] Grković, V., *et al*., Assured Capacity, Total Assured Capacity and Dispatchability of Serbian Power System and Power Plants – A Contribution the Research, *Proceeding*s, Thermal Power Plants 2020, Zlatibor, Serbia, 2020, postponed due to COVID-19 pandemic
[16] Grković, V., *Competitiveness of Energy Technologies* (in Serbian), Prometej, Novi Sad and the National Petroleum Committee of Serbia – the World Petroleum Council, Belgrade, Serbia, 2020
[17] Steffen, B., Weber, C., *Efficient Storage Capacity in Power Systems with Thermal and Renewable Generation*, EWL Working paper No. 04/2011, Chair for Management Science and Energy Economics, University of Duisburg, Essen, Germany, 2011
[18] Ferreira, H. L., *et al.*, Characterisation of Electrical Energy Storage Technologies, *Energy*, *53* (2013), May, pp. 288-298
[19] Dan, G., *et al*., An Integrated Energy Storage System Based on Hydrogen Storage, in: *Advances in Energy Systems Engineering*, (Ed. Kopanos G. M., *et al*.), Springer, New Yotk, USA, 2017, pp. 771-801
[20] Karalis, C., Muhl, M., Interaction of Renewable and Conventional Energies – Large-Scale Battery Systems as a Connecting Link, *VGB PowerTech*, (2017), 1/2, pp. 46-49
[21] Benesch, W. A., Karalis, C., Large-Scale Storage Options under Special Consideration of 6 × 15 mw Battery Example, *VGB PowerTech*, (2017), 4, pp. 30-34
[22] Grković, V., Marginal Share of Renewable Energy Sources of Variable Electricity Generation – A Contribution the Concept Definition, *Thermal Science*, *19* (2015), 2, pp. 383-396
[23] ***, Capital Costs Estimates for Utility Scale Electricity Generating Plants, U.S. Energy Information Administration, 2016 http://www.eia.gov
[24] Breeze, P., *The Cost of power Generation*, Business Insight, Warwick, UK, 2010
[25] Zeller E., Totschung, G., The Future Role of Energy Storage in Europe, (in German), *VGB PowerTech*, (2016) 1/2, pp. 29-34
[26] Kather, A., Future Climate Friendly Electricity Supply with Fossil Fired Power Plants (in German), *VGB PowerTech*, (2011), 9, pp. 44-53
[27] Kisliakov, D., Pumped-Storage in Bulgaria – Developments, Current Situation and some Perspectives, *Energy Procedia*, *58* (2014), Dec., pp. 129-136
[28] ***, https://en.wikipedia.org/wiki/List_of_power_stations_in_Belgium, 2021.
[29] ***, https://ec.europa.eu/eipp/desktop/en/projects/project-32.html, 2021
[30] ***, https://repository.tudelft.nl/islandora/object, 2021
[31] ***, Entso-e transparency platform. https://transparency. entsoe.eu, 2018
[32] ***, http://www.iea.org/statistics/statisticssearch/, 2018
[33] ***, https://www.energy-charts.de/power, 2018
[34] ***, https://www.energy-charts.de/energy, 2018
[35] ***, Electro energy portfolio of EPS, 2019
[36] ***, Government of Serbia, Ministry for Energy and Mining: https://www.mre.gov.rs, 2020

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