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ASSESSMENT OF A HYBRID WIND-PV SYSTEM FOR POWER GENERATION IN URBAN AREAS: LITHUANIAN CASE STUDY

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Abstract. In recent years, the electricity consumption rapidly grew around the world and Europe. Despite the fact that the integration of renewable energy sources (RES) increased, fossil fuels still play the main role for power generation. As a result of that, a huge amount of pollutants every year are emitted, and the quality of the environment significantly decreased. One of the ways to solve this problem is to foster the development of RES integration in urban areas. The paper presents an analysis of renewable energy resources and investigates its influence on a hybrid wind-photovoltaic system for power generation. The results indicated that the maximum generated power from photovoltaic was recorded in June, with the 197 kWh/m^{2,} and the lowest in December, 13 kWh/m^2. To compare, the wind speed gains the largest values during the winter season and the lowest in summer. Taking into consideration the diurnal wind speed variations, the maximum wind speed values exist at 12-13 o'clock. The suggested small-scale hybrid wind-photovoltaic system can be used for power generation during the whole year in urban areas. The efficiency of the system depends on different scale wind and solar power plants, the influence of obstacles and meteorological conditions.

Keywords: RES, photovoltaic, wind turbine, urban areas.

Introduction

The increasing energy consumption unavoidably brings a negative impact on the environment. In 2014, 78 per cent of the global final energy consumption was produced from fossil fuels and just 19 per cent from renewable energy sources, where 9 per cent role account for the traditional biomass and 10 per cent for modern renewables (hydropower, wind, solar, geothermal and so on) [1]. The use of fossil fuels brings not only local negative impact on the environment but also global problems such as climate changes and decreasing ozone layer [2, 3, 4]. In order to decrease the use of fossil energy sources and cover energy demand, one of the ways could be the development of renewable energy sources (RES). However, the renewables such as wind or solar energy are very volatile and cannot ensure a constant power generation flow. Therefore, it is necessary to diversificate power generation sources [5].

In recent years, researchers pay more attention to small-scale hybrid RES power generation systems in urban areas. This provides an opportunity to install systems to smart grids and as a result of that, the residents play prosumers' role when they are electricity producers and consumers. In order to encourage the integration of such hybrid renewable sources systems, it is necessary to analyse the technical part; besides, the future RES systems development is closely related to the assessment of natural resources [6].

The paper presents the assessment of wind and solar potential of power generation for the Kaunas city in Lithuania. It analyses and suggests a hybrid wind-photovoltaic system and presents its efficiency.

Methods

In order to evaluate the probability of the density, the Weibull function is commonly used and widely adopted. This function approximates the wind speed distribution during a chosen period in equation 1 [7, 8].

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (1)$$

where c is the scale parameter; k is the shape parameter, and v is the wind speed. To count k and c parameters, equations 2 and 3 are used respectively.

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n}\right)^{-1} \qquad (2)$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} v_i^k\right)^{\frac{1}{k}} \qquad (3)$$

where v_i is the wind speed, which does not equal zero; n is the number of measurements. To evaluate the energy output of the wind turbine, equation 4 is used.

$P = \frac{1}{2}$ HYPERLINK https://lt.wikipedia.org/wiki/Ro↓(raid%C4%97)\o Ro (raidĂl) $v^3 A$ (4)

where ρ is the air density 1.2 kg/m^3 (normal conditions), v - the wind speed, A – the swept area.

The power output of photovoltaics assessed is based on solar radiation parameters and the efficiency of polycrystal (Sharp 260W one panel) photovoltaics.

Results

Evaluation of wind resources

Kaunas is situated in the centre of Lithuania. In Kaunas region, the southwest wind of the average 3.72 m/s speed prevails. 60 W/m^2 wind power density was estimated at 10 m height (Fig. 1).

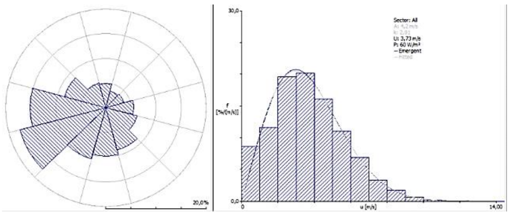

Figure 1. The wind rose and Weibull wind speed power density function in Kaunas

The wind speed probability function at 10 m height presented in Figure 2 demonstrates the variations of the wind speed in every season. It was noticed that the shape of Weibull function was very narrow in summer and it changed to wider in winter. Also, Weibull functions moved to the right side, which means a lower wind speed in summer and bigger in winter. Besides, the wider shape of the scale indicates large wind speed variations in winter, and a narrow smaller wind speed during summer, spring and autumn. However, in summer, the shape gains the highest value of probability function (Figure 2).

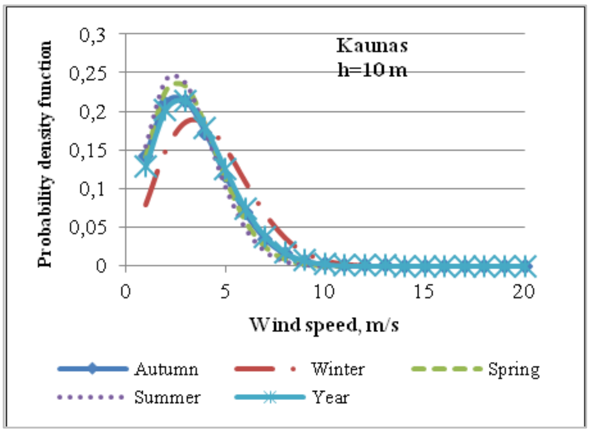

Figure 2. Weibull wind speed power density function in Kaunas in different seasons

In order to indicate diurnal wind speed variations, the 24-hour period analysis is presented in Figure 3. It was revealed that the wind speed from 9 p.m. to 5 a.m. is constant, and from 6 a.m. it increases. From 10 a.m., it is stable till 3 p.m., and from 4 p.m. significantly decreases.

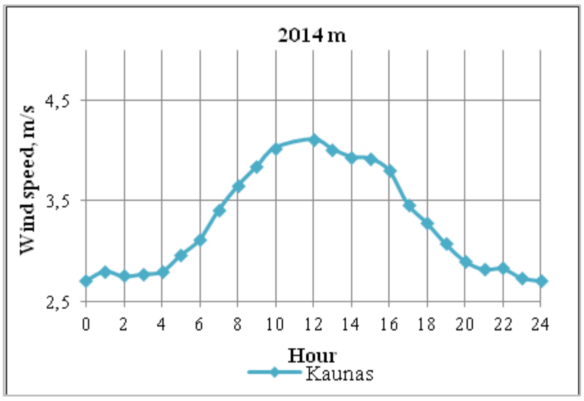

Figure 3. Diurnal wind speed variations

Diurnal wind speed variations could be explained by atmospheric processes in the boundary layer. During the day, the wind speed is higher and is impacted by solar radiation. When the sun is not so active, the pressure gradient between different distance points is lower because of the lower surface temperature. As a result of that, the wind speed is lower too. Later in the evening, when the sun sets, the wind speed becomes stable.

Solar energy potential

In order to understand the opportunity to install a photovoltaic system, the analysis of solar potential is necessary. This indicator can be evaluated by kilowatt-hours to a square meter. Annual solar radiation is presented in Figure 4. It can be noticed that in 2012-2015, solar radiation insignificantly increased from 1090 to 1124 kWh/m^2.

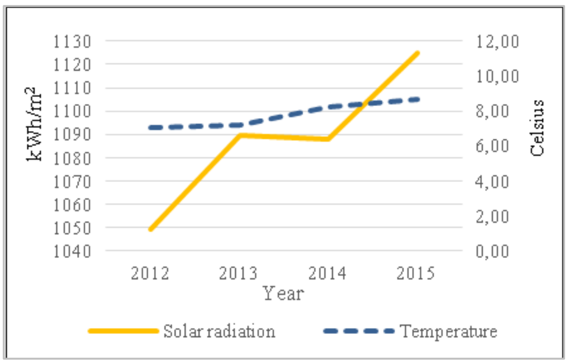

Figure 4. Annual parameters of solar radiation and temperature

The comparison of solar radiation during 2015 showed the huge volatility of values in different months. The best (highest) solar radiation was indicated in June, with 197 kWh/m^2, and the lowest in December, with 13 kWh/m^2. These results can be easily explained by the amount of solar radiation because in December days are the shortest and in June they are the longest.

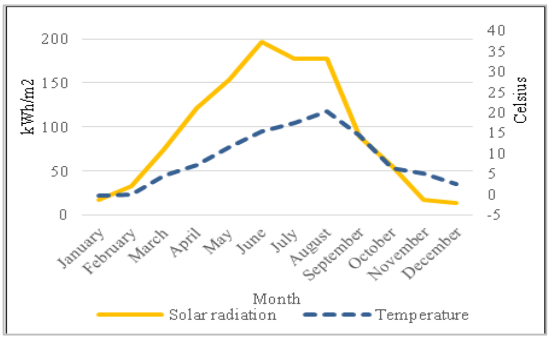

Figure 5. Monthly parameters of solar radiation and temperature in 2015

The analysis of solar radiation reveals a seasonal impact on power generation in photovoltaic systems. As it has been indicated before, the lowest energy variations were identified during the winter and the highest during the summer. On the contrary, the highest wind speed values exist in winter and the lowest in summer. A combined system can be used to cover residents' energy demand during the whole year.

Hybrid wind-PV system

The hybrid wind-PV system is suggested and consists of a 1.560 kW photovoltaic and 3 kW wind turbine. The photovoltaic system consists of 6 separated panels (each 260 W). An example of such a kind of a system is presented in Figure 6.

Figure 6. Example of a hybrid wind-photovoltaic system

Taking into consideration the local conditions and efficiency of inverters, monthly power output has been assessed. The efficiency of a wind turbine was taken for typical local conditions – 10 per cent, and photovoltaic 17 per cent. The main results are presented in Figure 7.

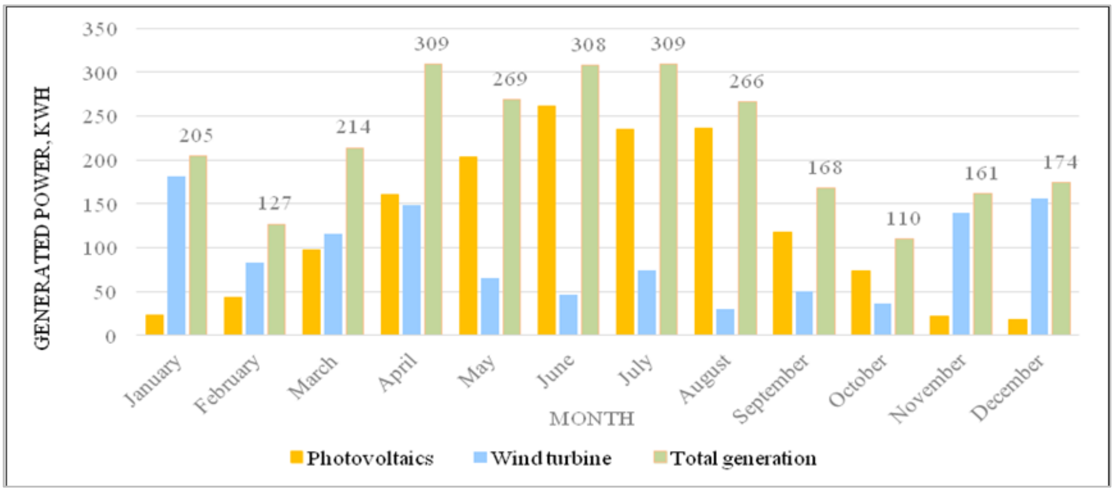

Figure 7. Estimated power output every month

It was indicated that the 1.560 kW photovoltaic system brings a higher part of power generation during 7 months per year and the wind turbine with the 5 kW installed capacity during 5 months per year. The largest total energy generation was recorded in April, June and July, with 308-309 kWh, and the lowest in February and October, with 127 and 110 kWh respectively.

The power capacity of the installed system is directly related to the energy demand. If a typical household energy demand varies in 100-150 kWh per month, the suggested system is sufficient to cover the energy demand, just it could be necessary to install an energy storage system. If the power consumption is higher, an external power source is necessary.

On the other hand, recently more smart grid systems have been developed, where residents are energy prosumers, i.e. they can produce, consume, sell and buy electricity [9, 10]. This is one of most important future directions and trends to supply and consume energy from RES systems in urban areas.

Conclusions

- Local conditions are directly related to the power output. A photovoltaic power plant generates the maximum energy in June, July and August, respectively 261, 234 and 236 kWh, and on the contrary, wind turbine during December and January, respectively 182 and 156 kWh.
- Taking into consideration local conditions and the efficiency of the hybrid system, the maximum power output is recorded from April to August (in limits of 309-266 kWh). During a one-year period, a 7-month photovoltaic and a 5-month wind turbine plays the main role in the power generation in the analysed hybrid power supply system.
- A hybrid wind – photovoltaic system can fully cover a monthly and annual private household energy demand. It could be an optimal solution for smart grids development, where the resident is both a power producer and consumer.

References

1. Wetstone, G., Thornton, K., Hinrichs-Rahlwes, R., Sawyer, S., Sander, M., Taylor, R., Rodgers, D., Alers, M., Lehmann, H., Eckhart, M., & Hales, D. (2016). *Renewables 2016 global status report.*
2. Peterson, T. D., & Rose, A. Z. (2006). Reducing conflicts between climate policy and energy policy in the US: The important role of the states. *Energy Policy, vol. 34, no. 5, p. 619–631.*
3. Mondal, M. A. H., & Denich, M. (2010). Assessment of renewable energy resources potential for electricity generation in Bangladesh. *Renewable and Sustainable Energy Reviews, vol. 14, no. 8, p. 2401–2413.*
4. Byrne, J., Hughes, K., Rickerson, W., & Kurdgelashvili, L. (2007). American policy conflict in the greenhouse: Divergent trends in federal, regional, state, and local green energy and climate change policy. *Energy Policy, vol. 35, no. 9, pp. 4555–4573.*
5. Walker, G. (2008). What are the barriers and incentives for community-owned means of energy production and use? *Energy Policy, vol. 36, p. 4401–4405.*
6. Zheng, Z. W., Chen, Y. Y., Huo, M. M., & Zhao, B., (2011). An overview: The development of prediction technology of wind and photovoltaic power generation. *Energy Procedia, vol. 12, p. 601–608.*
7. Weekes, S. M., Tomlin, S., Vosper, S. B., Skea, K., Gallani, M. L., & Standen, J. J. (2015). Long-term wind resource assessment for small and medium-scale turbines using operational forecast data and measure–correlate–predict. *Renew. Energy, vol. 81, p. 760–769.*
8. Weekes, S. M., & Tomlin, S. (2014). Comparison between the bivariate Weibull probability approach and linear regression for assessment of the long-term wind energy resource using MCP. *Renew. Energy, vol. 68, p. 529–539.*
9. Pearson, I. L. G. (2011). Smart grid cybersecurity for Europe. *Energy Policy, vol. 39, no. 9, p. 5211–5218.*
10. Niemi, R., Mikkola, J., and Lund, P. D. (2012). Urban energy systems with smart multi-carrier energy networks and renewable energy generation. *Renew. Energy, vol. 48, p. 524–536.*

HIBRIDINĖS SAULĖS-VĖJO SISTEMOS ELEKTROS ENERGIJAI GAMINTI URBANIZUOTOJE APLINKOJE TYRIMAS: LIETUVOS ATVEJIS

Anotacija

Pastaraisiais metais elektros energijos vartojimas visame pasaulyje, įskaitant ir Europą, ženkliai augo. Nors atsinaujinančių energijos išteklių (AEI) dalis pasaulyje vis didėja, iškastinis kuras vis dar sudaro pagrindinę dedamąją elektros energijos gamyboje. Dėl šios priežasties kasmet į atmosferą išmetamas didelis teršalų kiekis, kas sąlygoja blogėjančią aplinkos kokybę. Vienas iš būdų spręsti šią problemą - aktyviau plėtoti atsinaujinančių energijos šaltinių sistemas urbanizuotoje aplinkoje, kai vartotojas tampa elektros gamintoju. Straipsnyje pristatoma atsinaujinančių energijos šaltinių sistemos, integruotos urbanistinėje aplinkoje, jų analizė, pateikiami kiekybiniai ir kokybiniai rodikliai. Rezultatai rodo, jog pasirinkta saulės elektrinė daugiausiai elektros energijos -197 kWh/m^2, pagamina birželio mėnesį, mažiausiai gruodžio mėnesį - 13 kWh/m^2. Vėjo elektrinėje daugiausiai energijos generuojama, vyraujant didžiausiems vėjams žiemos metu, mažiausiai vasarą. Vertinant vėjo greitį dienos laikotarpyje, didžiausios vėjo greičio vertės fiksuotos 12-13 valandomis. Pasiūlyta saulės-vėjo hibridinė energetikos sistema leidžia vidutinio dydžio namų ūkį aprūpinti elektros energija visus metus, o sistemos efektyvumas priklauso nuo topografinių sąlygų, vėjo elektrinės aukščio, saulės intensyvumo, saulė modulių orientacijos kampo ir kitų rodiklių.

Raktiniai žodžiai: AEI, saulės elektrinės, vėjo elektrinės, urbanizuota aplinka.

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