archives
of thermodynamics
Vol. **44**(2023), No. 4, 221–241
DOI: 10.24425/ather.2023.149716

The impact of electrification of heating on the power grid for a selected area microgrids

MICHAŁ LASKOWSKI*
KRZYSZTOF KRAJEWSKI
PATRYK CHAJA
PAWEŁ ZAWADZKI
SEBASTIAN BYKUĆ

Institute of Fluid Flow Machinery, Polish Academy of Sciences,
Fiszera 14, 80-231 Gdańsk, Poland

Abstract In an era of changes in the electricity market, where the share of renewable energy sources is increasing and moving away from conventional coal-based energy, the electricity used for heating is gaining importance, for example to power heat pumps. They currently are one of the most common ways for heating buildings as an alternative to fossil fuels and biomass. In this article, the authors present an analysis aimed at answering the question whether using the concept of microgrids in Polish realities provides a feasible solution. Within the framework of this article, analyses were carried out by assuming the electrification of the heating installation of users in a local microgrid located in a selected location of the Polish low-voltage distribution network. The increase in electricity demand needed to generate the corresponding amount of heat was then estimated, and subsequently the impact of this demand on the microgrid was determined. In addition, in the article, the authors estimate the production of a prosumer PV installation at the selected location and analyze the level of autoconsumption of the generated electricity in the PV installation by the heat pump.

Keywords: Energy demand; Electrification of heating; Heat pumps; Power grid load; PV self-consumption; Smart metering; Smart grid

*Corresponding Author. Email: laskowski.michal@hotmail.com

1 Introduction

National and EU goals for the development of the energy sector focus on renewable energy, reducing harmful emissions, increasing energy efficiency and ensuring energy security. This leads to a gradual shift away from conventional fossil-based energy and the creation of new rules for the sector.

Distribution network operators are already facing a number of challenges, such as the increase in power from distributed high-power RES (renewable energy sources) installations connected to MV (medium voltage) and 110 kV networks, and the significant popularization of RES micro-installations connected to LV (low voltage) networks, leading to an effect of the popularization of RES micro installations power lines and a change in the direction of energy flows in the national electricity system. The solution to the increasing overload of power lines may be the concept of creating microgrids and electrification of heating in their area.

The conversion of surplus electricity production from RES to heat, referred to as 'power to heat' (P2H), increases the balancing capacity of microgrids and increases their flexibility. It also reduces the costs of modernization and development of the power infrastructure, increases the possibility of RES development and can contribute to reducing heating costs.

The most popular P2H technologies today are [1]:

- electric resistance boilers,
- electrode electric boilers,
- resistance heaters,
- heat pumps.

The topics addressed in this article are also reflected in other research papers [2–7] on the issues of the impact of electric heating on the power grid. The problem we are facing today in the context of the sharp reduction of fossil fuels supplied from the East makes the topic of energy transition in Poland gain a lot of momentum. In the presented work, the authors try to find an answer regarding the possibility of replacing fossil fuel heat sources with other types of heat sources powered by electricity, such as heat pumps, and what is their impact on the stability of electricity grids.

2 Description of research methodology

In this article, the technical feasibility of electrifying heating in the area of a dedicated microgrid by replacing conventional heating sources with heat pumps was investigated. This change is dictated by the significantly higher energy efficiency compared to traditional solutions used in Polish households, i.e. coal or pellet fuel boilers. Heat pumps have an energy efficiency factor of more than 3 compared to other technologies, whose efficiency factor is around 1. The energy efficiency factor informs us about the ratio of the heating energy obtained to the energy input in fuel and, in the case of heat pumps, in electricity. The higher the value of the coefficient, the more efficient the source. In the case of heat pumps, this coefficient depends on the design of the pump and the temperature of the heat source. The efficiency of heating with a heat pump, defined as the COP (coefficient of performance) [16], is greater the smaller the temperature difference between the upper source (e.g. water in the heating system) and the lower source (e.g. ground or groundwater).

As part of the study, the electricity consumption of consumers throughout the calendar year was analyzed. In the next step, based on the averaged volume and energy intensity, the heat demand of residential and commercial buildings in the selected area was calculated. For municipal buildings in this area, the calculation was based on the consumption of fuel oil. For the purpose of conducting the study, the demand for domestic hot water in households and commercial buildings was also calculated, based on the methodology in the Prime Minister's Decree. The study then examined what the electricity consumption profiles of the different types of heat pumps are. The demand for electricity and domestic hot water of consumers as well as heat pumps over the entire calendar year was summed to determine the days on which the so-called peak and valley loads occur. Then, for the day with the highest demand (summer and winter) for electricity, it was analyzed what the load on the power grids at the designated location of the microgrid equipped with heat pumps looks like for all consumers.

In addition, due to the growing popularity of prosumer RES installations, an analysis of the heat pumps' ability to autoconsume electricity produced by prosumer PV (photovoltaics) installations was made. For this purpose, the average instalation in the microgrid area as well as the energy production of the PV installations were determined for specific hours of the year, and compared with the energy demand of the heat pumps.

The simulations and analysis below will answer the question of how the replacement of traditional boilers with heat pumps will affect loads on the electricity grid.

3 Descripion of the microgrid

As part of the analysis, a village located in the northeastern region of Poland was selected as the location of the microgrid study area. It is a municipality which has a total population of more than 1 800. The municipality houses 52 MV/LV (medium voltage/low voltage) substations. Based on the analysis of electricity demand in the entire municipality, it was decided that the study would analyze the area with the highest consumption, concentrated in the area of 8 MV/LV substations in the central part of the municipality and covering 261 consumers, including: residential and commercial consumers, the City Hall, an elementary school and the Fire Department. Type of municipality: rural. Location: Northeastern part of Poland. The breakdown by tariff group is shown in Table 1. Data on electricity consumption by consumers in the area of the microgrid under study is actual data and comes from PGE (Polish Energy Group) internal materials.

Table 1: Number of electricity customers by tariff and electricity consumption.

Tariff	Number of electrical energy consumers	Power contracted (kW)	Energy consumed in 2021 (kWh)	(%)
B23	1	$\sim$ 800	1 439 725	56.3
C11	13	$\sim$ 170	110 155	4.3
C12b	4	$\sim$ 20	82 730	3.2
C12a	19	$\sim$ 315	301 986	11.8
G11	176	$\sim$ 1900	416 737	16.3
G12	12	$\sim$ 100	32 919	1.3
G12w	36	$\sim$ 550	174 647	6.8
SUM	261	$\sim$ 3855	2 558 898	100.0

3.1 Electricity demand analysis

A yearly average hourly demand profile was created for the tariff customers shown in the table above, which is based on energy consumption data from MV/LV substations, see Fig. 1.

The distribution of energy demand by month of the year was also examined, see Fig. 2. The highest average hourly energy demand in the area of the studied microgrid was 747.6 kWh and the highest average monthly consumption in the month of March was 641.41 kWh. The lowest average

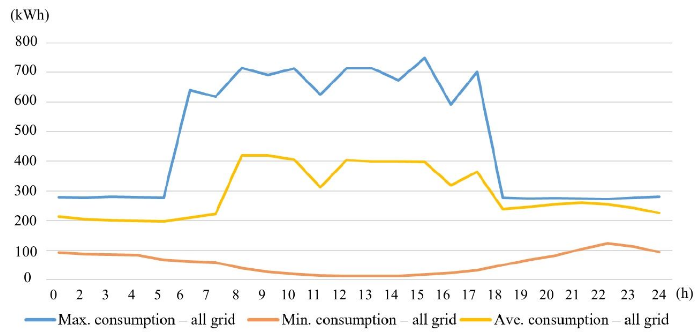

Figure 1: Average annual net energy consumption profile.

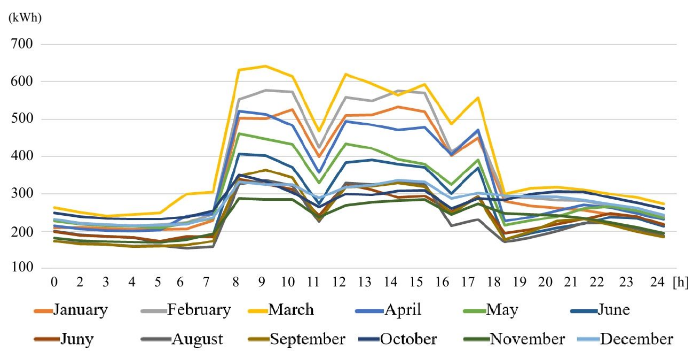

Figure 2: Averaged hourly profile of energy demand.

monthly energy consumption of 173.98 kWh was recorded in the month of August.

3.2 Analysis of heat and hot water demand

The distribution of average hourly temperature was obtained from archive data for building energy calculations for the 1972–1992 from the Ministry of Development and Investment, for a station in Ostrołęka, located not far from the microgrid. This hourly profile is shown in Fig. 3.

Based on the average hourly temperatures for Ostroleka, the occurrence frequency of several temperatures as well as other characteristic values were examined, as shown in Tables 2–3. (Own study based on data for energy calculations of buildings, Energy performance of buildings, Ministry of Investment and Development in Poland.)

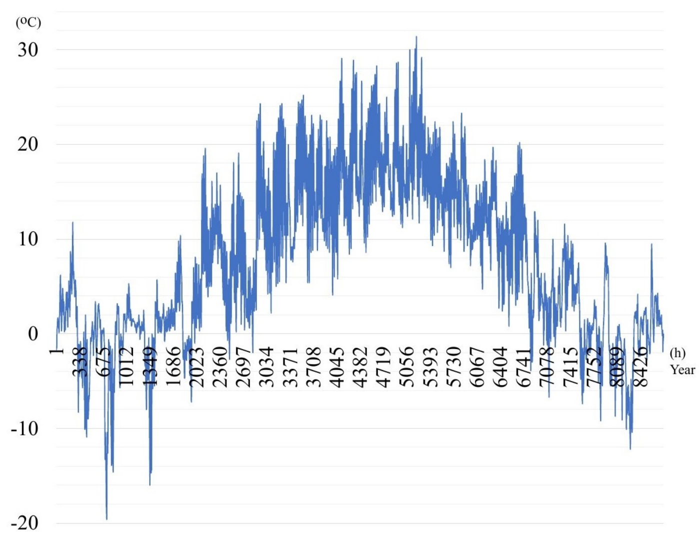

Figure 3: Hourly average temperature for the period 1972–1992 [8].

Table 2: Determination of the number of hours and days by temperature range.

Temperature	Hours	Days
below 0°C	1537	64
below –5°C	405	16
below –10°C	116	4
below –15°C	16	0

Table 3: Characteristic temperature values.

Type	Temperature
Lowest hourly-average outside temperature	–19.6°C
Annual average temperature	7.8°C

The analysis of heat demand in the microgrid area will apply to 260 customers including: 224 households (G tariff for electricity), 33 business customers, and 3 public utility customers (a school, the Municipal Cultural Centre and Library and the Municipal Office). The B tariff customer, which has its own biomass heat source, has been excluded from the analysis. Based on the report *Development Strategy of the Municipality of Miastkowo for*

2017–2024 [9], it was estimated that in 2015, the average floor area of apartments in the vicinity of the studied microgrid was 93.6 m^2, while the average number of persons per apartment was 3.82. The average number of persons for the rural municipality is in line with the study *Rural households compared to other types of households* [10], in which the average number of persons per farmer household in 2014 was determined to be 3.93 persons. For the purposes of further analysis, it was assumed that the total of 856 people live in the analyzed households, while commercial buildings are used by 66 people (2 people per facility).

The averaged area of a single-family house in first quarter 2022, according to [11], is 134.5 m^2. Averaging the Central Statistical Office (GUS) 2022 index with the average for Miastkowo, we get an average floor area of 114.05 m^2. However, as the average area for business facilities is estimated as 2 times the usable area for an individual consumer, this translated into an average area of 228.1 m^2 for business.

Heat demand can be divided by purpose into: central heating (CH) and domestic hot water (DHW).

3.3 Heat for central heating

For the purpose of estimating the heat demand of buildings, the energy classification of buildings according to the Association for Sustainable Development, shown in Table 4 was used.

Table 4: Energy classification of buildings [12].

Energy class	Energy rating	Indicator EA kWh/m2/year	Construction period
A+	Passive	<20	
A	Low energy	20-45	
B	Energy efficient	45-80	
C	Medium energy efficient	80-100	
D	Moderately energy-intensive	100-150	From 1999
E	Energy intensive	150-250	From 1998
F	highly energy-intensive	>250	From 1982

Assuming that most of the facilities in the microgrid area are 20th century buildings with varying levels of thermal insulation, for the purpose of estimating the demand for central heating, it was assumed that all buildings (households and business customers) are in Class D and the EA index (indicating the energy intensity class of the building) was assumed to be 110 kWh/m^2 per year.

The following formula was used to calculate the annual heat demand for central heating of all the analyzed buildings, except for the municipal ones for which the guide *How to Plan the Heat Demand of a Municipality* was used [25].

For residences (buildings):

$$Q_{W,co} = V_{CO,i}\, L_i\, P_{pu}\,,$$

where: V_{CO} – unit annual heat demand for CH (kWh/m^2/year); L_i – number of reference units, number of objects; P_{pu} – usable floor space (m^2).

For business (33 buildings):

$$Q_{W,co} = 110 \cdot 33 \cdot 228.1 = 828.0 \text{ MWh/year.}$$

The total annual heat demand for this group of buildings, estimated in this way, was 3638.2 MWh.

On the other hand, the heat demand for heating public facilities was calculated on the basis of the annual consumption of fuel oil used to heat municipal buildings. The municipality consumed 46 119 liters of oil with a calorific value of 38.8 MJ/litre in the year under review. The efficiency of oil boilers was assumed at 90%. The total annual demand of the analyzed municipal buildings was estimated at 447.4 MWh.

The total annual central heating demand of the buildings in the microgrid area was thus estimated at 4 0855 MWh.

3.4 Domestic hot water

Estimating the demand for domestic hot water (DHW) is not a straightforward task due, among others, to the following factors: water temperature, uneven intake throughout the days of the week and seasons of the year, changing population, and the quality and quantity of fixtures at the consumption points.

In order to estimate the demand for hot water, the Ordinance of the Minister of Infrastructure of November 6, 2008 was used, in which, in Appendix No. 5, a methodology for calculating the energy performance of a building, dwelling or part of a building constituting an independent technical and utility whole, not equipped with cooling systems, was specified.

In this methodology, a formula for determining the annual useful heat demand and hot water correction factors *kt* and daily hot water consumption for residential buildings of different types *Vcw* [13] is specified.

4 Compressor heat pumps

The simplest heat pump or cooling device is an energy device with the reverse action of a heat engine. This device takes in low-temperature heat and using, additional energy, gives off high-temperature heat. Analogous to a liquid pump where there is a 'liquid lift', in a heat pump there is a 'temperature lift'. Under the right conditions, the energy delivered to the system is several times less than the heat received at low temperature. This quotient depends mainly on the temperature difference. The heat delivered at high temperature is the sum of the above two.

Heat pumps and refrigeration equipment accomplish the above by subjecting the refrigerant through a series of thermodynamic transformations according to the Linde dry cycle, during which the refrigerant changes its state of aggregation between liquid and gas. To evaporate the refrigerant in the evaporator, the supplied low-temperature heat is used, while to condense the refrigerant in the condenser, high-temperature heat must be received. These units are also equipped with a compressor and a throttling valve to ensure the appropriate refrigerant pressure differential needed to achieve different evaporation and condensation temperatures.

We distinguish between these devices according to the desired effect, i.e. if the desired effect is the removal of heat through the device then it is a cooling device (e.g. air conditioner, refrigerator), while if the desired effect is the supply of heat through the device then it is a heat pump (e.g. space heating, DHW heating). If the device is able to operate in both modes, then we are talking about the possibility of operation of the device in reverse mode. This requires the use of an appropriate design and special components, such as a four-way valve, or heat exchangers that can operate as a condenser or evaporator.

Heat pumps are classified by their lower and upper heat source, e.g. the simplest air-to-water heat pump extracts heat from the ambient air, and gives the heat back to the water in the central heating system. The upper heat source is also used to heat domestic hot water or air directly, for example, in air ducts. In the case of standard heat pumps, the temperature of the upper source medium does not exceed 65°C, but there are heat pumps operating in the transcritical circuit, where the medium is CO_2, which can supply water at temperatures as high as 90°C. As the temperature of the upper source medium increases, the coefficient of performance of heat pumps decreases, so it is most efficient to use heat pumps with underfloor heating systems, where a temperature of 30°C to 35°C is sufficient.

Atmospheric air is most often used as a lower heat source, due to its simplicity, availability and by far the lowest cost. Such systems achieve a lower efficiency than systems using heat from the ground or groundwater. To extract heat from the ground, ground heat exchangers are most often used, among which several types can be distinguished according to the depth of application. However, the use of waste heat, e.g. in industry, allows you to achieve the most efficient and economical type of heat pump. An inverse relationship can be observed between the availability and cost of the bottom source and the efficiency of heat pump operation.

4.1 Analysis of electricity demand for heating and domestic hot water by heat pumps

According to the Low Carbon Management Plan for the Municipality of Miastkowo for 2016–2020, the main fuel used for residential purposes was wood, which accounted for more than 87% of the fuel used. Electricity came next with a share of 12.15% [14]. The public buildings in the microgrid area are equipped with heating sources fired by fuel oil.

In order to ensure the greatest possible security in heat supply while reducing emissions, it was assumed that there will be a significant electrification of heating in the microgrid area, i.e. replacement of 100% of boilers with heat pumps powered by energy from local RES sources. The heat sources at municipal facilities are planned to be replaced with high-temperature heat pumps, while household heating systems would be replaced with low-temperature heat pumps connected to other heating devices in a water loop, which can be compared to a heating microgrid. Such a solution will optimize heating costs while reducing emissions and, at the same time, avoid the significant costs of developing a district heating network in a rural municipality, which makes the economic justification for their development in rural areas unviable.

Analyzing the volume of central heating demand for a standard house in the microgrid area with an area of 114.05 m^2 and an estimated central heating demand of 110 kW/m^2/year was derived from the performance characteristics of an air source heat pump with a compressor capacity of

2500 W in a typical single-family house [18]. Electricity demand over 12 months for the given type of heat pump is shown in Fig. 4. Atmospheric air temperature from the Meteonorm 7.2 database for Ostroleka was used. The demand for heat and hot water was 18.014 kWh, and electricity consumption was 4.733 kWh.

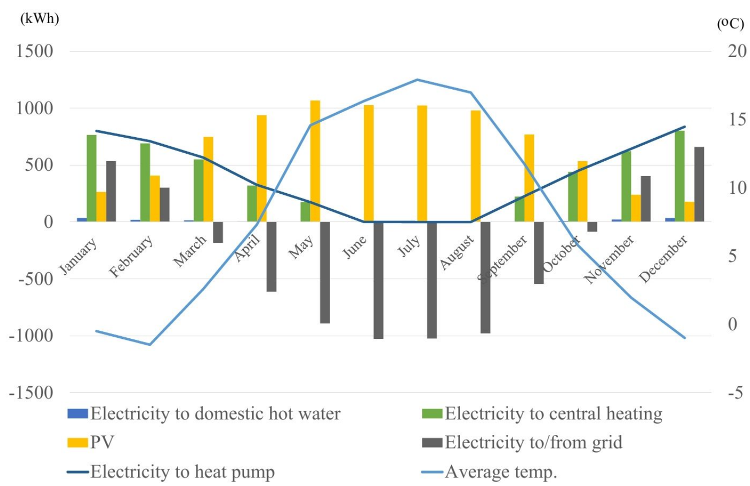

Figure 4: The average monthly electricity demand for an air source heat pump of 2.5 kW.

The air source heat pump operated with a dependent efficiency described by the equation

$$\mathrm{COP} = 0.0013T_a^2 + 0.0671T_a + 2.8787 - 0.0565\,(T_g - 45)\,,$$

where T_a is the ambient air temperature, T_g is the temperature of the upper heat pump exchanger.

However, for the characteristics of a ground-source heat pump with a compressor power of 1.875 W in the model house, the demand for heat and domestic hot water was 18.485 kWh, and the electricity consumption was 3.401 kWh. In Fig. 5, you can observe the electricity demand of the ground source heat pump.

The ground source heat pump operated at the dependent efficiency described by the equation [17]:

$$\mathrm{COP} = -0.125T_g + 9.575,$$

where T_g is the temperature of the upper heat pump exchanger.

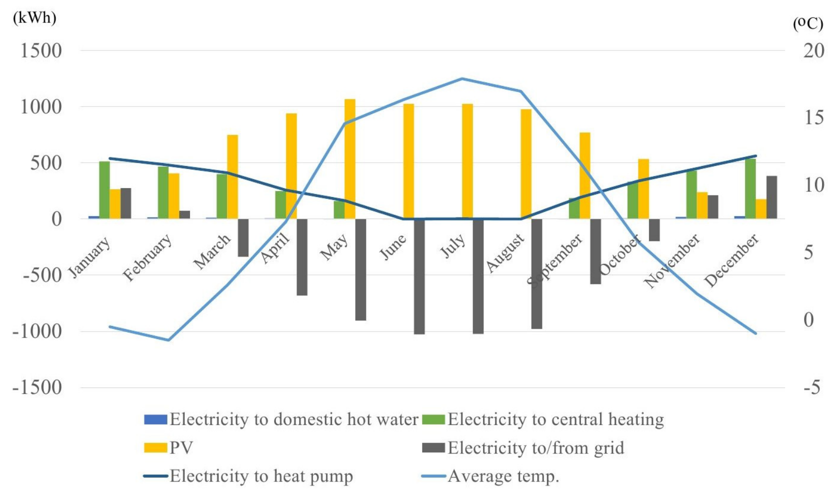

Figure 5: The average monthly electricity demand for a ground source heat pump with a capacity of 1875 W.

For both heat pumps, the COP relationship was assumed by averaging data from product data sheets of Viessman [19], Vaillant [20] and Daikin [21], the Port PC market report [15] and laboratory tests conducted by the Fraunhofer Institute [21]. A bottom heat source temperature of 10°C was assumed for the ground source heat pump.

In addition, the analysis was enriched by characterizing the production from an 8 kW prosumer installation according to Global Solar Atlas parameters [23] where the average annual production for a 1 kWp panel in the microgrid area is 1.022 MWh. The average production from 1 kWp for individual hours and months is shown in Fig. 6. As can be seen in Figure 6, the most energy produced by PV will be between April and August, between 9 am and 2 pm.

The electricity consumption waveforms for the compressor pump for two characteristic days of the year:

- the day with the highest electricity consumption throughout a day in winter;
- the day with the highest electricity consumption throughout a day in summer;
- are presented below in Figs. 7–8. From the point of view of grid operation and the simulations performed, the days with the highest

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5					9	21	12					
5 - 6				18	54	60	50	28	1			
6 - 7			27	115	160	161	141	116	76	12		
7 - 8		32	152	254	297	289	267	247	204	126	7	
8 - 9	60	156	274	385	420	404	386	377	329	224	103	45
9 - 10	158	237	366	476	505	480	468	467	415	298	155	114
10 - 11	189	274	409	508	537	518	506	502	439	320	170	134
11 - 12	196	288	428	508	528	507	494	499	439	334	185	147
12 - 13	194	288	422	478	497	482	476	478	417	324	174	139
13 - 14	165	265	385	427	440	431	425	426	358	265	135	105
14 - 15	102	186	291	340	361	359	356	349	276	177	70	31
15 - 16	3	94	184	239	264	279	274	255	176	75	0	
16 - 17		2	76	130	157	178	174	151	72	1		
17 - 18			2	33	59	76	75	49	5			
18 - 19				1	14	29	25	4				
19 - 20						3	1					
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	1,066	1,820	3,016	3,912	4,302	4,279	4,128	3,949	3,208	2,157	1,000	714

Figure 6: Average production from 1kWp of installed PV capacity in the microgrid area (Wh) [26].

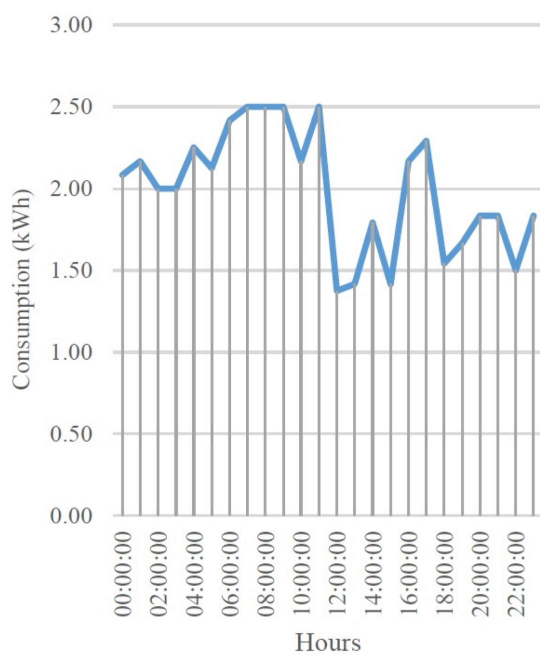

Figure 7: Hourly usage profile of the day with highest usage in winter – 31 Jan. 2021.

electricity consumption put the most strain on the power lines at the selected location. According to the diagram shown in Fig. 7, the selected microgrid location has a single-sided power supply.

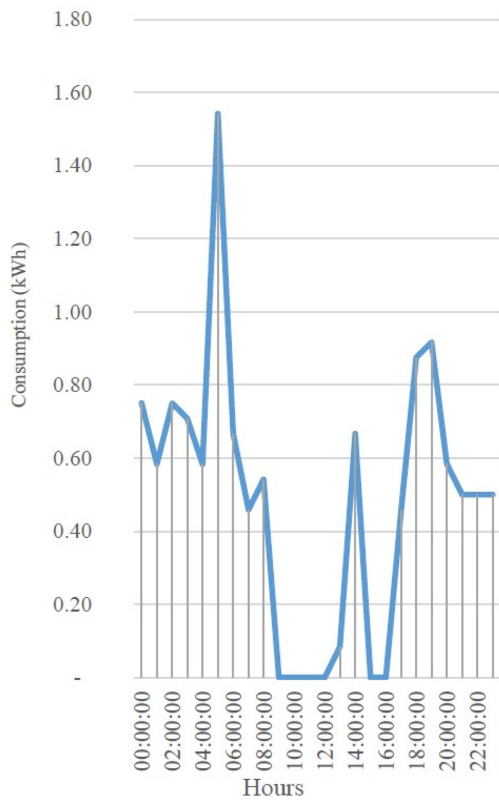

Figure 8: Hourly usage profile of the day with highest usage in summer – 21 Sept. 2022.

5 Impact of heating electrification on the microgrid area

The operation of the grid infrastructure was simulated using the NEPLAN tool [26]. In line with the purpose of this article, it was investigated what the network load looks like before and after the implementation of heat pumps at all customers. Simulations were carried out on a selected location with 8 medium-voltage to low-voltage (MV/LV) transformer stations, from which electricity is supplied to 261 consumers. Figure 9 shows the network diagram at the selected microgrid location. Information such as the length of individual power lines or the number of consumers comes from

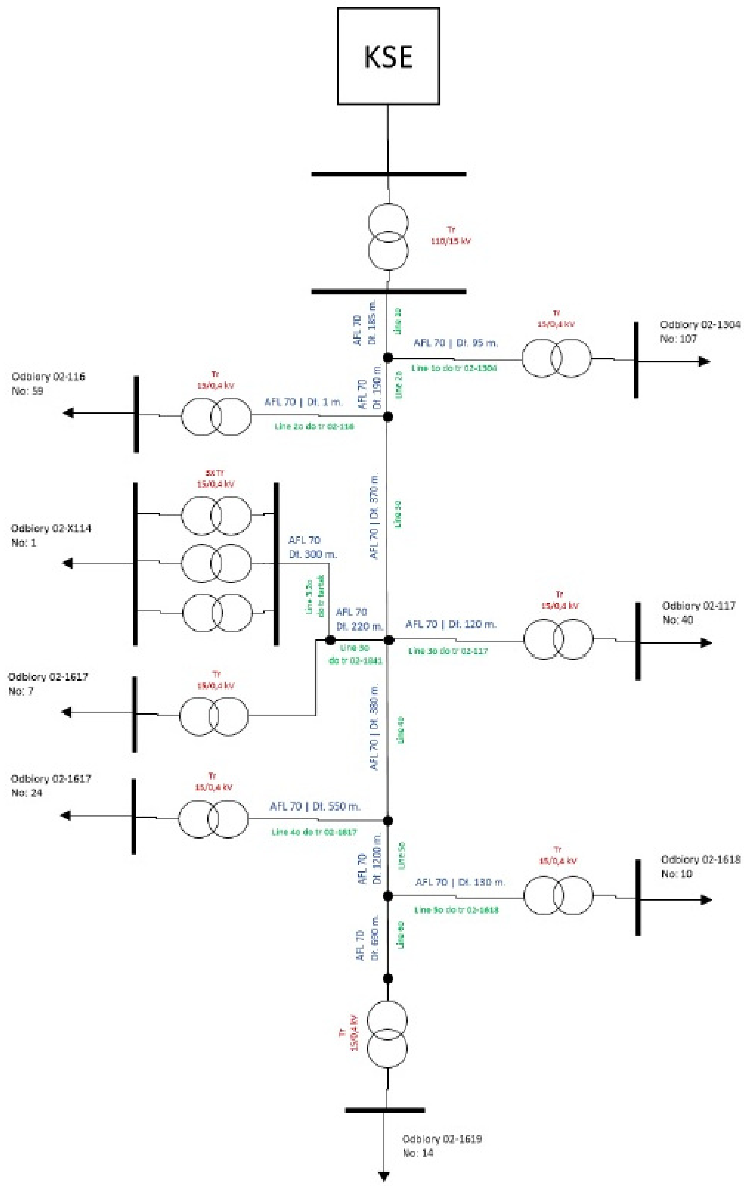

Figure 9: Diagram of the network in the selected location of the microgrid.

map readings found in geoportal360.pl. Other data such as cross-sections of power lines and parameters of transformers, were selected on the basis of available information from the electricity distributor in the indicated area – PGE Dystrybucja S.A. According to information on the electricity supplier's website, AL70 mm^2 type lines, or those with larger cross-sections, are used for the main medium-voltage overhead lines. For the purposes of our study, it was assumed that the main lines from the 110 kV/15 kV substation and the individual lines running to the 15 kV/0.4 kV substation are made of AL70mm^2 type overhead lines. The characteristics of the transformers adopted for the simulation can be found in Table 5.

Table 5: Parameters of oil transformers adopted for simulation [27].

Indicator	Unit	Value
Sn	MVA	0.16–0.63
Ug (Ur)	kV	15.75
Ud1 (Ur2)	kV	0.42
Ud2	kV	–
uzwgd1 (ukr1)	%	4.22
ΔPcu (uRr1)	kW	2.343
ΔPFe	kW	0.28
io	%	0.6
Connection group	–	Yzn5
Adjustment range	% or kV	$15.75 \pm 3x2.5\%$

The MV line supplying 8 transformer stations has a single-sided supply. The demand for electricity at each substation is presented in Table 6. The performed network simulation, allowed us to verify the loads on the lines in the designated microgrid location. The network parameters for the selected days in the winter and summer peaks are presented below. As can be observed, there is no overloading on any of the line sections in the microgrid. The total energy consumption in the winter peak was almost 930 kWh, while in the summer peak it was more than 675 kWh.

In accordance with the purpose of the study, it was assumed that all consumers (261 households) will be equipped with a heat pump with the parameters given in Section 4.1. It is therefore necessary to check whether the network infrastructure in the microgrid will manage to operate in the

Table 6: Summary of electricity consumption for peak and valley demand.

Station number	Maximum consumption for peak winter 08.03 hours 15 (kWh)	Maximum consumption for peak summer 20.07 hours 9 (kWh)	Maximum consumption for peak winter 08.03 hours 15 (with pumps) (kWh)	Maximum consumption for peak summer 20.07 hours 9 (with pumps) (kWh)
02-116	46.32	8.43	193.2	98.9
02-117	17.52	4.68	118.3	66.7
02-1304	81.51	19.89	348.7	184.5
02-1617	15.20	1.40	75.2	38.3
02-1618	6.05	0.25	29.8	14.9
02-1619	9.05	4.00	44.2	25.7
02-1841	6.00	14.16	22.3	24.2
02-X114	747.60	622.50	750.1	624.0
Total	929.25	675.31	1581.8	1077.3

summer peak and winter peak without failure. For this purpose, the maximum electricity consumption was read from the heat pump's annual energy demand waveforms and these values were added to the selected summer peak – 20 July 9:00 am – 675.31 kWh and for the winter peak – 08 March 3:00 pm – 929.25 kWh. The results are presented in Table 6.

The results presented in Table 6, which are the maximum electricity consumption of consumers in the summer and winter peaks, were assigned to individual substations as load, subsequently it was then checked how the change in demand caused by the implementation of heat pumps affects the operation of power lines.

A comparison of the obtained results of the network load in the microgrid with primary electricity consumption and equipped with heat pumps at all customers, can be found in Figs. 10 and 11.

In light of the results presented, it can be seen that the largest load changes occur in Line 10, where the load increases from about 12% to more than 20% in the winter peak and from about 9% to about 14% in the summer peak. The smallest changes occur in the line with the highest consumption feeding the sawmill where the impact of switching the few electricity consumers fed by this line to heat pumps has a small impact on the line's load of less than 0.5 p.p. (percentage point) in both the summer and winter peaks.

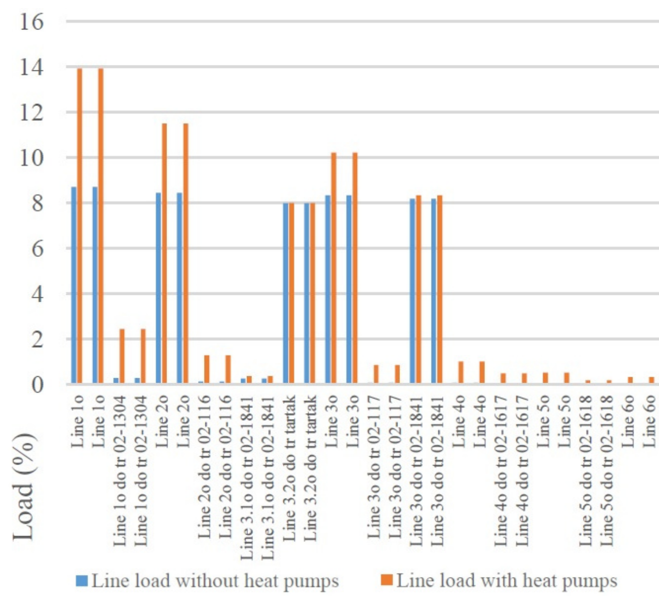

Figure 10: Load results of individual power lines for the summer peak.

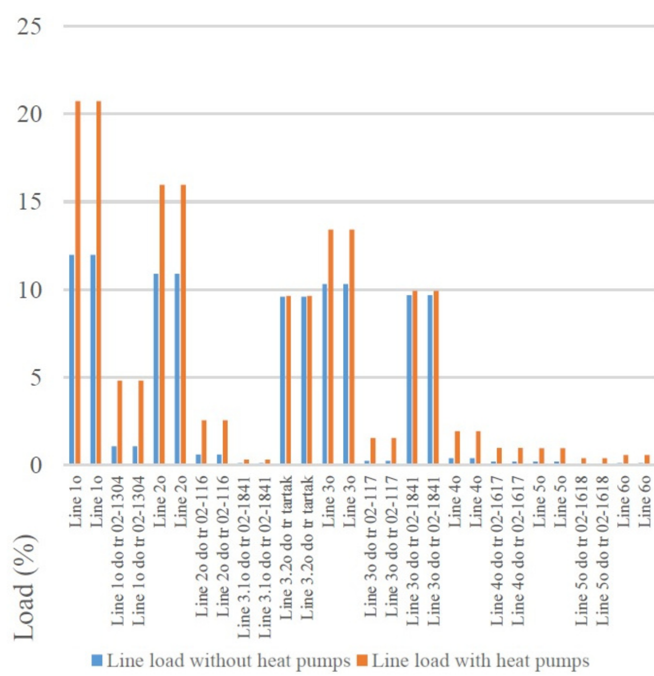

Figure 11: Power line load results for the winter peak.

6 Conclusions

The analysis of the impact of switching the heating source of electricity consumers from traditional sources to heat pumps on the power grid section shows that this action does not affect the energy security of the residents of the analyzed power grid section.

Additional analysis of the electricity demand profile of the heat pumps and the electricity generation profile of the PV source showed a 100% consumption level of PV energy during the winter peak in the months of November-February, i.e. the period of highest electricity demand by the heat pumps, and a near-zero autoconsumption level during the summer peak in the months of June-August, i.e. the period of highest electricity generation by the PV system.

In the paper, the authors tried to demonstrate that, in the case of using heat pumps as alternative sources to heating with traditional fuels (coal, biomass, gas), the application of the above approach for the analyzed microgrid system allows full electrification of heating without loss of network parameters and its stable operation.

Acknowledgements

This article was developed as part of the implementation PhDs carried out at IMP PAN and PGE Polska Grupa Energetyczna S.A.

Received 16 May 2023

References

[1] Institute for Renewable Energy: *Renewable energy sources in the heating industry Technologies that will change reality.* Energy Forum, IEO rep., May 2020 (in Polish).

[2] Lowes R., Woodman B., Speirs J.: *Heating in Great Britain: An incumbent discourse coalition resists an electrifying future*, Environ. Innov. Soc. T. **37**(2020), 1–17.

[3] Marszal-Pomianowska A., Widé J., Le Dréa J., Heiselber P., Bak-Jense B., de Cerio Mendaz I.D.: *Operation of power distribution networks with new and flexible loads: A case of existing residential low voltage network.* Energy **202**(2020), 117715.

[4] Askeland K., Rygg B.J., Sperling K., *The role of 4th generation district heating (4GDH) in a highly electrified hydropower dominated energy system – the case of Norway.* Int. J. Sust. Energ. Plann. Manage. **27** (2020), Spec. Iss., 17–34.

[5] Bolkesjo T.F., Kirkerud J.G., Tromborg E.: *Power market impacts of increased use of electricity in the heating sector.*) Int. Conf. on the European Energy Market, EEM, 2017, 7981955.

[6] Protopapadaki C., Saelens D.: *Heat pump and PV impact on residential low-voltage distribution grids as a function of building and district properties*. Appl. Energ. **192**(2017), 268–281.

[7] Radziszewska W., Bugaj M., Łuniewski M., Hoogsteen G., Chaja P., Bykuć S.: *Testing of a price-based system for power balancing on real-life HVAC installation in real life*. Bull. Pol. Acad. Sci. Tech. Sci. **70**(2022), 2, e140690.

[8] Ministry of Investment and Development in Poland: *Data for energy calculations of buildings* (in Polish). https://www.gov.pl/web/archiwum-inwestycje-rozwoj/dane-do-obliczen-energetycznych-budynkow (accessed 20 July 2023).

[9] Municipality of Miastkowo: *Development Strategy of Miastkowo 2017-2024*. Miastkowo 2017 (in Polish).

[10] Urban S.: *Farm households in comparison with the other type of household*. Probl. Small Agr. Holdings **4**(2016), 93–107 (in Polish). doi: 10.15576/PDGR/2016.4.93

[11] Central Statistical Office: *Construction in Q1 2022*. 10 June 2022. GUS, Warszawa 2022 (in Polish).

[12] http://www.drevohaus.pl/?drev=energooszczednosc (accessed 24 Sept. 2022.).

[13] Minister of Infrastructure: "The methodology of calculating the energy performance of a building and a dwelling or a part of a building constituting a separate technical and utilitarian unit, as well as the method of drawing up and models of their energy performance certificates". DzU Nr 201/2008, poz. 1240 (in Polish).

[14] Municipality of Miastkowo: *Low-carbon management plan for the municipality of Miastkowo for 2016-2020*, Miastkowo 2015 (in Polish).

[15] Lachman P., Rączka J., Schnell C., Wróbel P.: *Scenarios for electrification of heating in single-family buildings in Poland until 2030*, Port PC, 2020 (in Polish).

[16] Magni M., Venturi E., Ochs F., Dermentzis G.: *Impact of the European building energy requirements on the heat pump market*. In: Proc. 4th IEA Heat Pump Conf.15-18 May 2023, Chicago, 2023, 778.

[17] Klein K., Huchtemann K.: *Numerical study on hybrid heat pump systems in existing buildings*. Energ. Buildings **70**(2014), 441–454.

[18] Ghoubali R., Byrne P.: *Simulation study of a heat pump for simultaneous heating and cooling coupled to buildings*. Energ. Buildings **72**(2014), 141–149.

[19] https://www.viessmann.pl/pl/budynki-mieszkalne/pompy-ciepla.html (accessed 22 Jan. 2023).

[20] https://www.vaillant.pl/klienci-indywidualni/produkty-i-systemy/grupy-produktowe/pompy-ciepla/ (accessed 15 Jan. 2023).

[21] https://www.daikin.pl/pl_pl/product-group.html (accessed 22 Jan. 2023).

[22] https://wp-monitoring.ise.fraunhofer.de/wp-effizienz//download/final_report_wp_effizienz_en.pdf (accessed 14 Jan. 2023).

[23] https://globalsolaratlas.info/detail?c=53.078971,21.711731,11&s=53.132354,21.735764&m=site&pv=small,180,38,1 (accessed 19.04.2023).

[24] https://pgedystrybucja.pl/strefa-klienta/przydatne-dokumenty/akordeon-przydatne-dokumenty/zestawienie-wytycznych-do-budowy-systemow-elektroenergetycznych (accessed 25.02.2023).

[25] Upper Silesian Regional Energy Conservation Agency (GRAPE), Foundation for the Efficient Use of Energy (FEWE), Krakow Development Office (BRK) under the direction of Dr. Jan Uruski: *Guidebook on how to plan heat supply in the Municipality*, Katowice – Kraków 1998 (in Polish).

[26] NEPLAN: *Load Flow and Short Circuit*, https://www.neplan.ch/ (accessed 18 Apr. 2023).

[27] https://www.prosper.com.pl/katalogi/Nowa-plus/transformatory.pdf (accessed 10 Apr. 2023).