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DROOP-BASED LOAD CONTROL

RESEARCH ARTICLE

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Improving renewable self-consumption in residential DC nanogrids through droop-based load control

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ABSTRACT

This paper investigates droop-based load control as a decentralized strategy for maximizing renewable self-consumption (RSC) in a residential direct current (DC) nanogrid without local energy storage. While droop control is widely applied to sources and storage units in DC microgrids, its systematic use for residential load management remains insufficiently explored. In this study, a residential DC nanogrid model was developed in the PLECS simulation environment using measured photovoltaic (PV) generation and household load profiles from two single-family homes in Estonia. The model follows a 350 V DC architecture and includes a PV converter, an active front-end (AFE) grid interface, and controllable thermal loads.

Droop control was applied to a geothermal heat pump and the defrosting function of a heat recovery ventilation (HRV) system using an energy-based calibration approach to maintain equivalent weekly energy consumption. Simulation results over a one-week measurement period show that baseline operation achieved an RSC of 0.51. Applying droop control to the geothermal heat pump increased RSC to 0.69, corresponding to a 26% improvement, by shifting consumption towards periods of high PV generation. In contrast, droop control of the HRV provided only marginal improvement due to its smaller energy share. Combined droop control of both loads resulted in an RSC of 0.69.

The results demonstrate that droop-based load control can significantly enhance renewable energy utilization in residential DC nanogrids without battery storage.

1. Introduction

The increasing electrification of residential buildings, combined with the growing integration of distributed renewable energy sources, has intensified the need for more efficient and flexible power distribution architectures. One emerging trend in this context is the adoption of direct current (DC) distribution systems in residential applications [1–4]. The primary motivation for this transition is improved energy efficiency. Since many modern household appliances and electronic devices inherently operate on DC power, DC distribution eliminates the need for an additional rectification stage in power electronic converters. For instance, the removal of a single power factor correction (PFC) rectifier stage can reduce conversion losses by up to 25% [4]. In addition to efficiency improvements, DC systems offer further advantages, including the absence of synchronization requirements, elimination of reactive power compensation, and reduced total harmonic distortion issues [5].

Modern residential buildings are no longer passive energy consumers but increasingly incorporate local generation technologies such as photovoltaic (PV) systems and small-scale wind turbines. Furthermore, many households include battery storage systems to balance renewable production and consumption. When combined with DC distribution, these elements enable more efficient integration of renewable sources and reduced conversion losses. Such systems can be viewed as small-scale DC microgrids or nanogrids, typically ranging from 10 to 100 kW [1]. These nanogrids are capable of satisfying local demand and exporting surplus energy to the utility grid.

A typical residential DC nanogrid consists of a centralized DC bus interconnecting generation units, storage devices, and electrical loads, as illustrated in Fig. 1. In most configurations, the nanogrid is connected to the main alternating current (AC) grid via a bidirectional power electronic interface, commonly referred to as the active front-end (AFE) converter. The AFE enables power exchange with the utility grid, allowing surplus energy to be exported or additional power to be imported when local generation is insufficient.

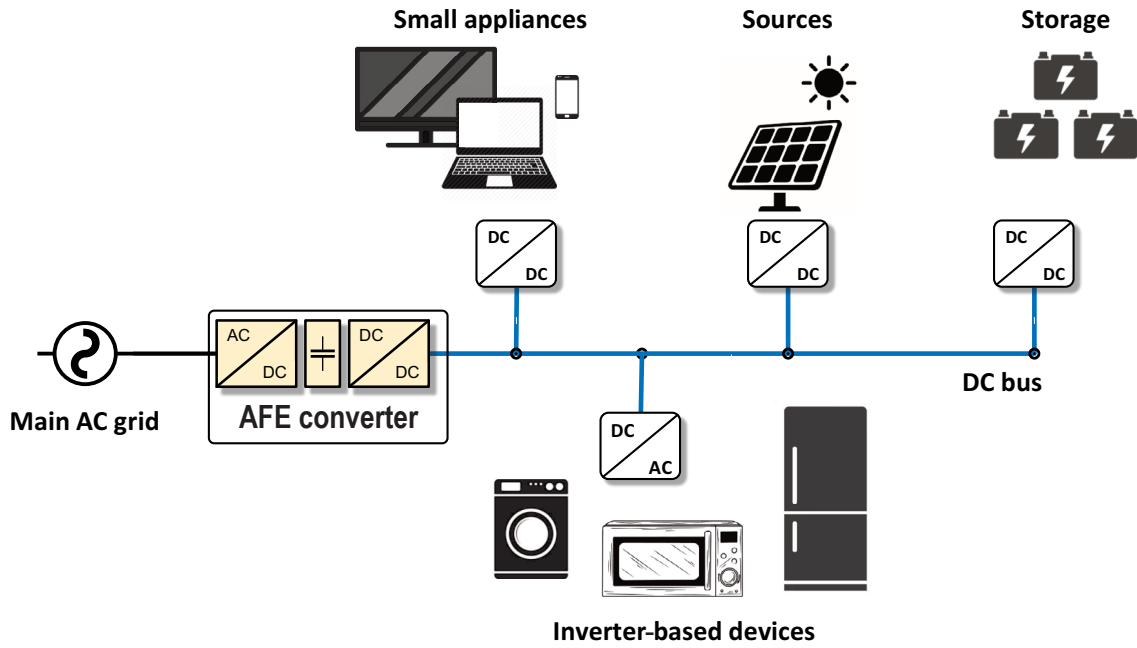


Fig. 1. Typical structure of a residential DC nanogrid.

The primary objectives of DC nanogrid control are to maintain a stable DC bus voltage and ensure appropriate power sharing among connected devices. These objectives can be achieved through centralized or decentralized control strategies [6]. Although centralized control offers high coordination capability, it requires extensive communication infrastructure and increased system complexity, which may limit its cost-effectiveness in residential applications. Consequently, decentralized control methods are generally preferred, with DC droop control being one of the most widely adopted techniques due to its simplicity and communication-free operation.

Most existing research on DC droop control focuses on the coordination of energy sources, grid interface converters, and energy storage devices [7–12]. In contrast, comparatively little attention has been given to droop-based load control in residential DC nanogrids. While some studies have explored load management in microgrids [13,14], and recent reviews have analysed residential demand flexibility [15], comprehensive investigations of droop-controlled loads within residential DC nanogrids remain limited.

Among residential loads, heat pumps (HPs) are particularly suitable for demand-side management (DSM) due to their relatively high electrical power demand and the inherent thermal flexibility. Previous studies have demonstrated that HP operation can be shifted or curtailed to reduce peak grid loading and provide DSM service. In [16], considerable load-shedding potential from HPs was demonstrated, coupled with thermal storage. Other studies have considered controlled HP operation jointly with electricity prices, network constraints, and PV generation, confirming that HPs can provide substantial flexibility to low-voltage networks [17].

HPs have also been investigated as controllable loads for direct AC grid support. Local control of HP water heaters based on the grid voltage has been proposed to mitigate voltage rise caused by high residential PV penetration [18]. In this

approach, HP operation is shifted towards periods of excessive PV generation to reduce reverse power flow while maintaining sufficient hot-water availability. Similarly, voltage-dependent droop control has been applied to variable-speed HPs in clustered distribution grids with high PV penetration [19]. By continuously adjusting compressor power according to the local AC voltage, droop-controlled HPs were shown to reduce critical grid states associated with high PV penetration. In particular, the droop characteristic directly modifies HP electrical consumption according to the voltage at its grid connection point.

The flexibility of HPs has also been exploited for frequency support. For example, in [20], coordinated primary frequency support from small- and large-scale HPs was investigated, demonstrating that controllable HP demand can contribute to improving the frequency response of the power system. More recently, frequency droop control of HPs has been proposed for integrated electricity and district-heating systems in isolated microgrids, where HP demand response was used to provide frequency regulation and facilitate the integration of variable renewable generation [21].

These studies demonstrate that the electrical consumption of HPs can be actively adjusted in response to the state of the power system and can therefore provide valuable flexibility. However, existing droop-based approaches have predominantly been developed for AC networks, where HP operation is modified to support grid voltage or frequency. In a residential DC nanogrid, the same underlying principle can be transferred to the DC bus, where bus voltage provides a direct indication of the local generation–consumption balance. This creates an opportunity to use the HP not primarily as an ancillary-service resource for the external AC grid but as a locally controlled flexible load whose consumption follows the availability of renewable generation.

To address this research gap, the current paper investigated the application of droop-based load control strategies

to enhance renewable self-consumption (RSC) in a residential DC nanogrid. A simulation model was developed using measured PV generation and household load data from two single-family homes in Estonia. The study focused on controlling major thermal loads to better align consumption with PV availability. Unlike previous droop-controlled HP applications primarily targeting AC grid voltage or frequency support, the proposed approach uses the DC bus voltage as a decentralized control signal to increase local utilization of PV energy. The results demonstrate that droop-based load management can significantly increase RSC and reduce grid dependence without the use of battery storage. However, it should be acknowledged that modifying the operating profile of building heating and ventilation systems may affect indoor thermal conditions and, consequently, occupant comfort. A comprehensive assessment of these effects would require a detailed thermal model of the building, including its thermal characteristics, indoor temperature dynamics, and relevant comfort constraints. Such a model was beyond the scope of the present study, which primarily focused on evaluating the feasibility and theoretical potential of droop-based residential load control for improving RSC. The results demonstrate sufficient potential to justify further investigation of this control approach. Future work should therefore incorporate a detailed building thermal model, allowing the impact of droop-controlled load management on indoor conditions and occupant comfort to be evaluated.

2. Data acquisition and analysis

The simulations were based on real-world data collected from two residential test sites located in North Estonia, near the capital city of Tallinn. Both sites were representative single-family homes. One site provided PV generation data, which were obtained from a 5 kW rooftop PV array connected to the AC bus through a 4.2 kW three-phase inverter. The other site supplied detailed household electrical load profiles. The load groups were aggregated into the following seven categories:

- 5.3 kW geothermal HP, providing both underfloor heating and domestic hot water;
- heat recovery ventilation (HRV), with power consumption ranging from 15 to 170 W, including an electric defrosting element with a rated power of 900 W;
- lighting – predominantly based on LED technology;
- sockets – general-purpose electrical outlets throughout the household;
- fridge/dishwasher – refrigeration and dishwashing appliances;
- cooking appliances – one induction hob and one electric oven;
- others – miscellaneous electrical loads not covered by the above categories.

To assess seasonal variations in household electricity consumption, measurement data were collected between January and June 2025. Clear seasonal trends can be observed by comparing the months of January (winter), April (spring), and

June (summer). In January, total electricity consumption amounted to 791 kWh, with the geothermal HP responsible for approximately 50% of the total demand (Fig. 2). This dominant contribution reflects the high heating requirements characteristic of Northern European winters. HRV accounted for 14% of consumption, while socket loads contributed 12%, both influenced by climatic conditions and occupant behaviour.

By April (Fig. 3), total electricity demand decreased to 490 kWh, representing a reduction of approximately 300 kWh compared to January. HP consumption declined to 204 kWh, corresponding to a 51% decrease, whereas HRV and socket loads remained relatively stable. The reduction in lighting demand is attributed to extended daylight hours during the spring season.

In June (Fig. 4), total household electricity consumption further declined to 327 kWh, which is 163 kWh lower than in April. HP energy use decreased by 81% relative to January levels, with the remaining 76 kWh primarily associated with domestic hot water production. Additionally, warmer ambient temperatures led to a 34% reduction in HRV energy consumption compared to April, as the electric defrosting function was no longer required. In contrast, the electricity consumption of cooking appliances, refrigerators, and dishwashers remained relatively constant, indicating limited sensitivity to seasonal weather conditions.

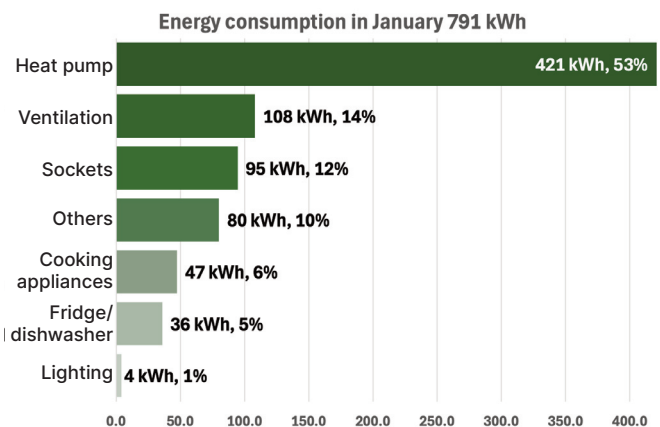


Fig. 2. Monthly energy consumption per appliance in January 2025.

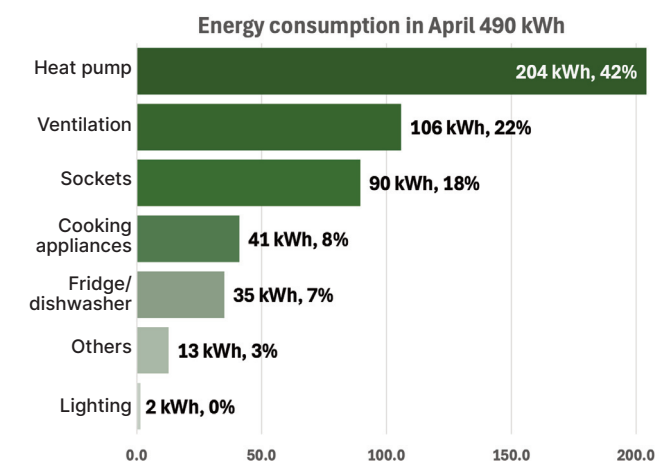


Fig. 3. Monthly energy consumption per appliance in April 2025.

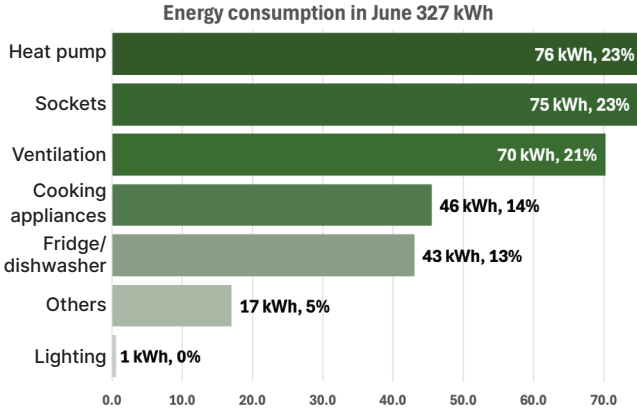


Fig. 4. Monthly energy consumption per appliance in June 2025.

The primary goal of this study was to maximize the local utilization of renewable energy through effective load control. From a load management and control perspective, winter may initially appear attractive due to the high electricity demand in Estonia. However, solar irradiance during this period is very low, resulting in negligible PV generation, which makes winter conditions unsuitable for this study.

During the summer months, the situation is reversed. Although PV generation is high, household electricity demand in Estonia is typically low, which limits the effectiveness of load control strategies. Based on the seasonal consumption analysis, April was selected as the most suitable test month, as it offers a balanced combination of moderate electricity demand and substantial PV generation (Fig. 3). This balance provides favourable conditions for evaluating load control strategies aimed at maximizing RSC.

In April, 82% of the household electricity was consumed by the geothermal HP (204 kWh), HRV (106 kWh), and general-purpose wall outlets (90 kWh). These loads therefore present the highest potential for improving energy efficiency and RSC. Since outlets are considered nonflexible and cannot be easily controlled, this study focused on modifying the operation of the HP and the HRV system. All other loads were handled as nonflexible and were used in the simulation without changes.

3. Droop control of loads

Droop control is a well-established method for managing multiple electrical sources in microgrids. Its main advantage lies in enabling parallel sources to share power proportionally without the need for additional communication. In AC microgrids, droop control relies on monitoring both frequency and voltage, whereas in DC microgrids it can be implemented solely through DC bus voltage measurements. As a result, DC droop control requires only a single sensor and provides a highly robust approach for power sharing.

Since loads can only consume power, the load droop characteristics exist exclusively in the positive power region, as shown in Fig. 5. The objective of this study was to investigate how load-based droop control can enhance renewable energy self-consumption. To achieve this, the load droop curves must exhibit a positive slope, meaning that power

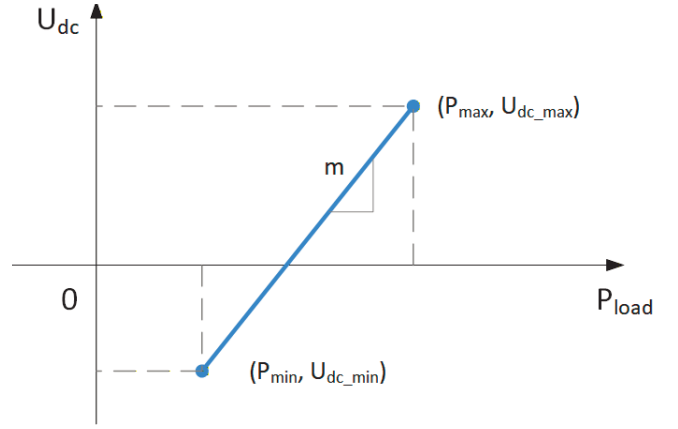


Fig. 5. Typical linear droop curve for loads.

consumption increases with rising DC bus voltage. The mathematical representation of the droop characteristic can be expressed using a point-slope linear equation, as presented below:

$$u_{dc}(t) - U_{dc_max} = m \cdot (p_{load}(t) - P_{max}), \quad (1)$$

where u_{dc} is the DC bus voltage, U_{dc_max} is the maximum DC bus voltage level, p_{load} is the load power, P_{max} is the maximum load power, and m is the slope of the droop curve (also known as the droop coefficient). The slope can be defined from two points on the droop curve as follows:

$$m = \frac{U_{dc_max} - U_{dc_min}}{P_{max} - P_{min}}, \quad (2)$$

where U_{dc_min} is the minimum DC bus voltage and P_{min} is the minimum load power. To model the droop control, the DC bus voltage is typically known, and the load power must be determined. From (1), the load power can be derived as follows:

$$p_{load}(t) = \frac{1}{m}(u_{dc}(t) - U_{dc_max}) + P_{max}. \quad (3)$$

The slope of the droop curve, commonly referred to as the droop coefficient, must be calculated individually for each load using (2). The droop control inherently limits the load power and enables power adjustment through appropriate selection of droop coefficients. Loads with higher droop coefficients exhibit slower changes in power, whereas lower droop coefficients result in faster power variations.

In general, there are two approaches to modifying droop coefficients: adjusting the power levels or altering the DC bus voltage limits. Since the maximum power level of an electrical device is predefined by the manufacturer and cannot be modified, the droop curves must be adjusted by changing the maximum and minimum DC bus voltage values and, in some cases, also the minimum power level.

4. Modelling the residential DC nanogrid

4.1. Model description

The residential DC nanogrid was modelled using the PLECS simulation environment. The electrical parameters of the model are shown in Table 1. The model comprises a PV converter, nonflexible electrical loads, geothermal HP, HRV, and

Table 1. Electrical parameters in the PLECS simulation model

Parameter	Value
DC bus voltage	350 ± 35 V
Maximum power of the HP	2300 W
Minimum power of the HP	0 V
Maximum power of the HRV	900
Minimum power of the HRV	0
Maximum power of the AFE	15 kW

an AFE converter, as illustrated in Fig. 6. A battery energy storage was not included in the model, ensuring that PV energy utilization depended exclusively on instantaneous local demand, with any surplus power exported to the main grid through the AFE.

To assess the effectiveness of energy flow control within the building, detailed switching models of the power electronic converters were not required and were therefore replaced with controlled current sources, as shown in Fig. 6. This simplification significantly reduced computational com-

plexity, enabling faster simulations and longer simulation time horizons.

The physical and thermal characteristics of the building were not explicitly modelled in this study. Therefore, the thermal impact of droop control could not be evaluated directly. Instead, an energy-based droop control approach was adopted. In this method, the droop control algorithm was calibrated to maintain the total weekly energy consumption of each load at its reference value, which was evaluated from logger data.

It was assumed that maintaining equal total energy consumption over the evaluation period would result in an equivalent heating effect. The same energy-based droop control principle was applied to the HRV unit.

The operation of each device in the residential DC nanogrid is directly governed by the bus voltage, which serves as the primary coordination signal. The bus voltage is allowed to vary within $\pm 10\%$ of its nominal value (i.e. ranging from 0.9 per unit (p.u.) to 1.1 p.u.), as indicated in Fig. 7. A voltage increase indicates that generation exceeds demand, resulting

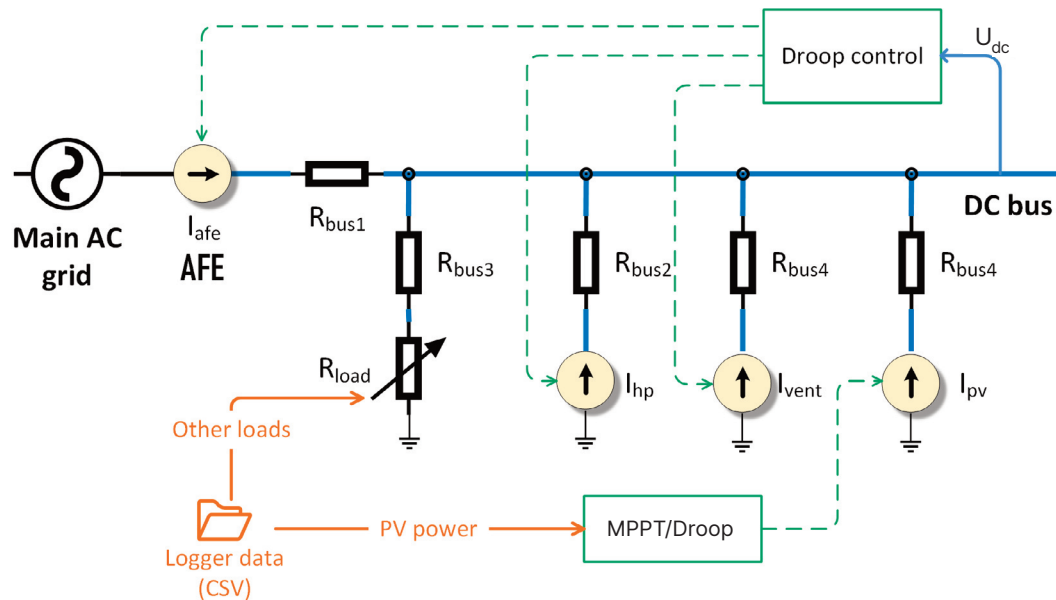


Fig. 6. Simplified model of the residential DC nanogrid.

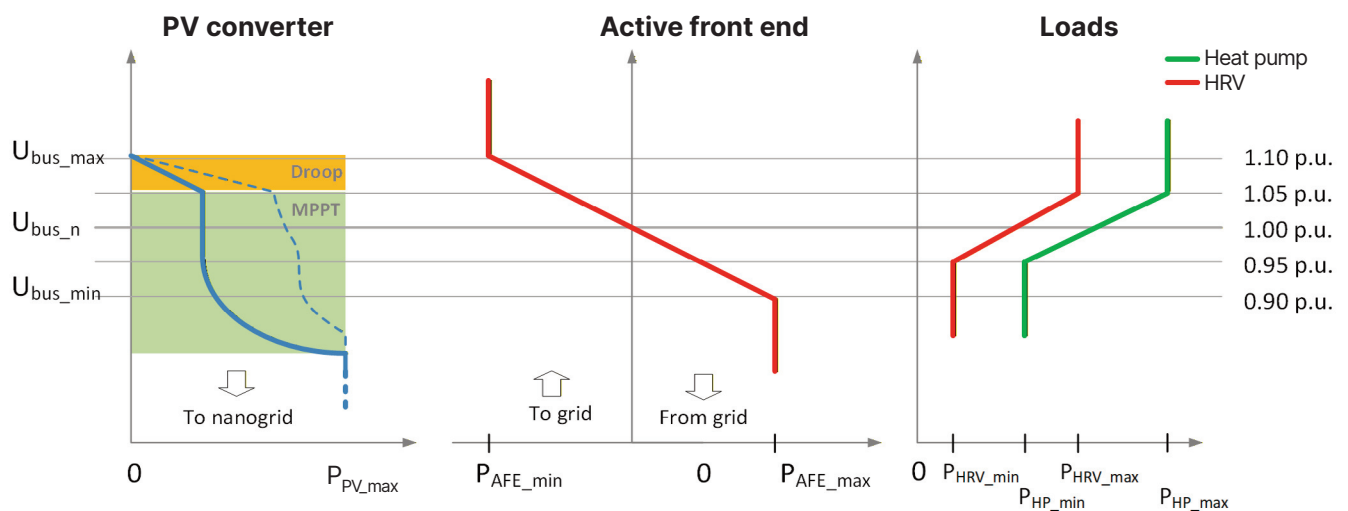


Fig. 7. Proposed load droop control strategy in the residential DC nanogrid.

in a surplus of energy, whereas a voltage decrease reflects insufficient generation relative to load, signalling an energy deficit.

The AFE converter serves as a bidirectional interface between the main grid and the DC nanogrid. The droop coefficient of the AFE was determined based on the parameters provided in Table 1. Its droop characteristic was defined over the full DC bus voltage range, from 0.9 p.u. to 1.1 p.u. (Fig. 7). When the bus voltage exceeds the nominal value, the AFE injects power into the main grid; conversely, when the voltage falls below nominal, it draws power from the grid.

Under normal operating conditions, the PV converter operates in maximum power point tracking (MPPT) mode to maximize energy extraction. In the present study, a detailed MPPT algorithm was not required, as the PV power data were obtained from a real inverter and directly used in the simulation. However, when the DC bus voltage exceeds 1.05 p.u., this indicates that local generation surpasses instantaneous consumption. To prevent excessive voltage rise and ensure system stability, the PV converter switches from MPPT to droop control mode, reducing its output power proportionally to the bus voltage deviation.

The geothermal HP and HRV unit were modelled as droop-controlled current sources. The droop control algorithm (3) was applied to the measured power profiles imported from the comma-separated values (CSV) file. Following the droop-based power adjustment, the resulting power values were converted into corresponding current references and injected into the DC bus within the simulation model. All other loads were considered as nonflexible and were simulated as a variable resistor (Fig. 6).

Since loads can only consume power, their output power remains positive. Unlike the AFE, the droop characteristics of loads may have different slopes and do not necessarily span the entire allowable bus voltage range, as shown in Fig. 7. Investigating the impact of different load droop placements on system performance constituted the primary objective of this study.

4.2. Used datasets

To ensure realistic system behaviour, the simulation incorporated measured PV production data and detailed household load profiles, as introduced earlier. These time-series datasets for PV generation and load consumption were imported into the simulation model as CSV files (Fig. 6). The PV generation data were recorded with a sampling interval of 10 s, whereas the load profiles were recorded at 1 min intervals. The two datasets were synchronized within the PLECS simulation environment, with linear interpolation applied between consecutive data points to provide continuous input signals throughout the simulation.

Although the PV generation and load consumption data were recorded in different years and at different test sites, their combined use is justified, as PV production and household electricity demand in conventional residential settings are statistically independent. The datasets were aligned by month and obtained from geographically comparable locations to ensure consistency in climatic conditions.

In contrast to many previous studies that consider relatively short simulation intervals (ranging from seconds to hours), this work employs measured data over a one-week period. The authors consider this duration appropriate for evaluating the performance of microgrid load control strategies, as it captures daily variability while maintaining manageable computational complexity.

The measurement data originated from conventional AC-based houses but were adapted for DC nanogrid simulation. The model followed the Dutch DC low-voltage standard NPR 9090, which proposes 350 V as the nominal DC bus voltage. Corresponding current levels were calculated from the PV and load power data accordingly.

5. Simulation and results

April was selected as the test period, as discussed previously. The simulations were conducted over a one-week interval (7 days), using measured data imported from CSV files and appropriately scaled for the simulation environment. In the model, 60.48 seconds of simulation time represented one week of real operation.

In this study, load droop control was applied to the geothermal HP and the HRV unit to evaluate their effect on RSC, which is calculated as follows:

$$RSC = \frac{E_{PV} - E_{grid}}{E_{PV}}, \quad (4)$$

where E_{PV} denotes the total energy generated by the PV system and E_{grid} represents the portion of the PV energy that was not consumed locally but was instead exported to the grid. The RSC value ranges from 0 to 1. An RSC of 1 indicates that all PV-generated energy is consumed locally, whereas an RSC of 0 signifies that the entire PV output is exported to the grid.

During the analysed week, total PV production amounted to 155 kWh, while total electricity consumption reached 170 kWh. However, not all household loads are flexible or subject to curtailment. In this study, only the geothermal HP and the HRV unit were considered for droop-based control. Together, these two loads accounted for a total energy consumption of 111 kWh during the analysed period. In our previous study using the same dataset, a load-shifting strategy resulted in a maximum RSC value of 0.79. The objective of the present study was to investigate how the implementation of droop control influences the system performance and alters the achievable RSC values.

5.1. Initial situation

In the simulation, measured datasets from two geographically similar locations were combined to model a representative residential DC nanogrid. In the initial configuration, droop control was applied only to the AFE converter, which was responsible for exporting surplus energy to the main AC grid. A positive AFE power indicates energy import from the grid, whereas a negative AFE power corresponds to energy export to the grid, as shown in Fig. 8.

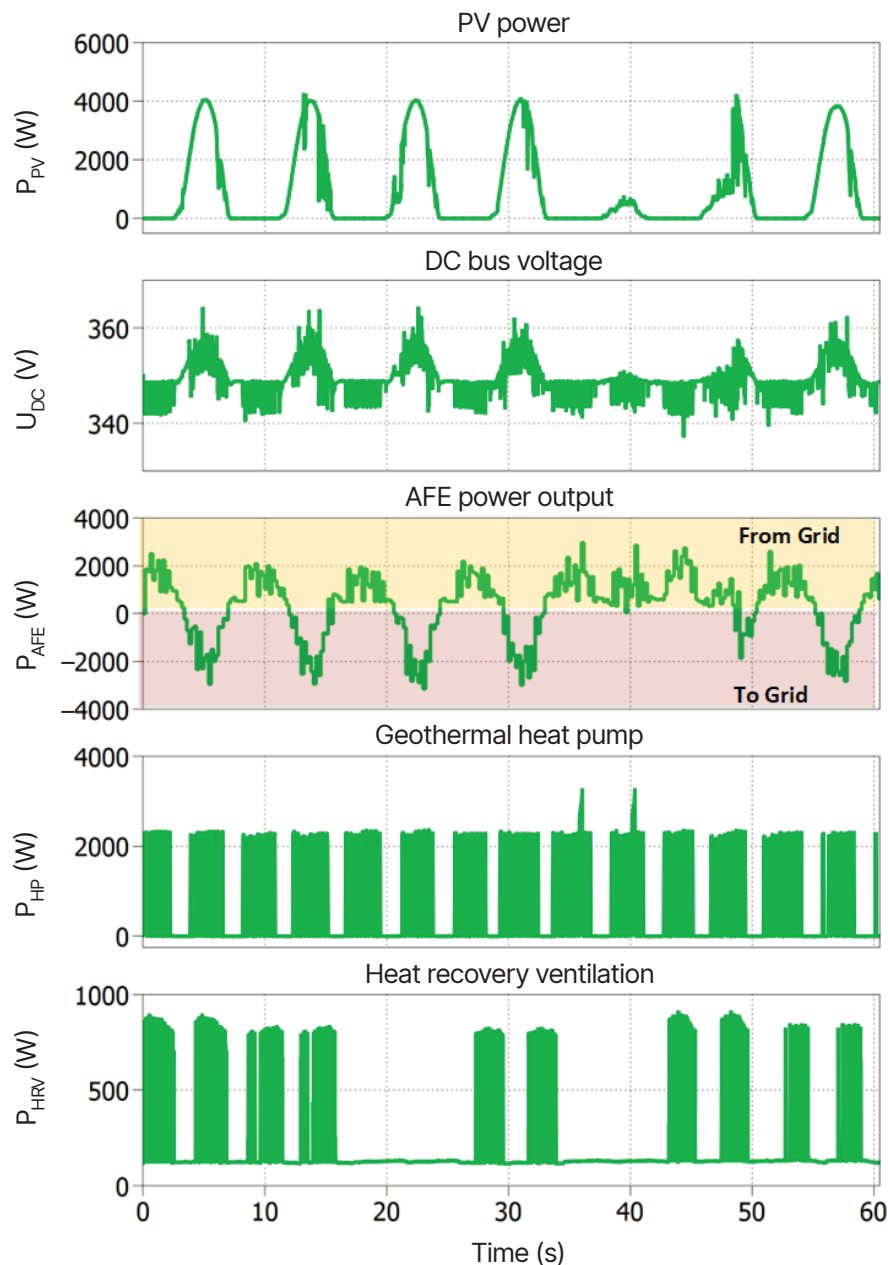


Fig. 8. Initial state of the residential nanogrid. The time axis is scaled such that 60.48 s corresponds to one week of real time.

During the first five days, PV generation exhibited relatively stable behaviour, reaching a peak output of approximately 4 kW (Fig. 8). However, on the fifth day, cloud cover significantly reduced peak generation to around 800 W. On the sixth day, intermittent cloud conditions caused fluctuations in PV output between 1 kW and 4 kW. The DC bus voltage closely followed the PV generation profile. During daytime operation, the bus voltage rose by approximately 10 V above its nominal value of 350 V due to PV production. In contrast, during nighttime periods without PV generation, the bus voltage fell below the nominal level, and the AFE began importing energy from the main grid, as shown in Fig. 8.

The geothermal HP operates in approximately 12-hour intervals, with an average maximum power demand of 2.3 kW. On two occasions, the power increased to 3.3 kW due to the activation of the auxiliary electric heater. Such activation may occur for several reasons, including sudden increases in heating demand, defrost cycles, or the execution of a legionella protection cycle for domestic hot water. However, in the

present simulation model, the nominal maximum power value of 2.3 kW was used. In typical operation, the first heating cycle occurs during daytime hours and partially overlaps with PV production, whereas the second cycle takes place during nighttime hours and is therefore supplied entirely by the utility grid, as shown in Fig. 8.

The HRV unit runs continuously, maintaining a steady base load of about 125 W. During periods of sub-zero outdoor temperatures, moisture contained in the exhaust air may condense and freeze on the heat exchanger surface. This ice accumulation restricts airflow and reduces the efficiency of heat recovery. To maintain proper operation, the HRV system incorporates an electric defrosting function that periodically removes the ice buildup. In the analysed configuration, the defrosting system had a peak power demand of up to 900 W (Fig. 8).

A simulation with the current PV and load profiles gave the following results: total energy consumed was close to 170 kWh; from that, HP was 96 kWh and HRV defrosting

15 kWh, energy import from the grid was 132 kWh and the RSC reached 0.51.

5.2. Droop-controlled heat pump

In Fig. 9, a simplified diagram of the HP and its connection to the heating system is shown. Droop control can be implemented on an inverter-driven HP, allowing its power consumption to be continuously adjusted according to the DC bus voltage.

Applying droop control exclusively to the geothermal HP reduced its maximum power demand from 2.3 kW to 1.8 kW. By appropriately tuning the droop coefficient, the primary HP operation was shifted towards daytime hours, thereby improving synchronization with PV generation, as shown in Fig. 10. During nighttime periods, the HP power was limited to below 400 W.

The droop-controlled operation of the HP also influenced the behaviour of the AFE converter. Compared to the baseline case, the average nighttime power imported through the AFE was reduced by approximately 50%, decreasing from 2 kW to 1 kW (Fig. 10). Consequently, the RSC increased to 0.69, representing a 35% improvement over the initial scenario.

5.3. Droop-controlled heat recovery ventilation

In the case of the HRV system, droop control was applied exclusively to the defrosting function, while the base ventilation load of approximately 125 W remained unchanged. Consequently, indoor air quality was assumed to be unaffected by the control strategy. The HRV defrosting function

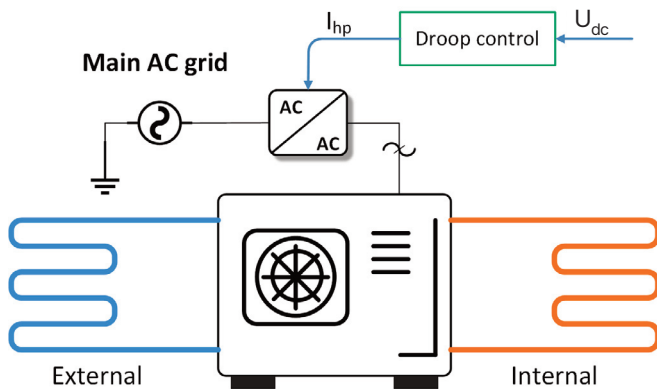


Fig. 9. Simplified diagram of the droop-controlled HP.

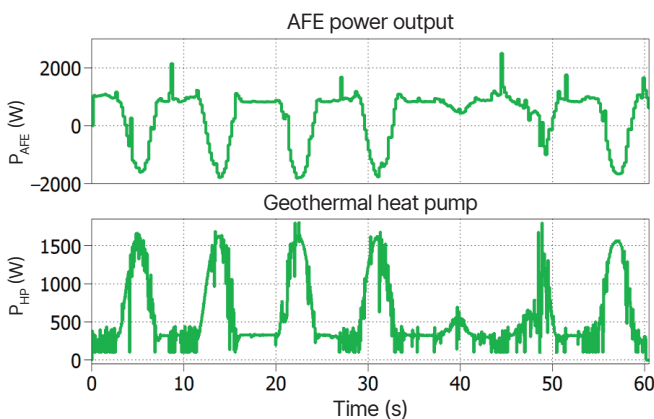


Fig. 10. Geothermal HP working in droop control.

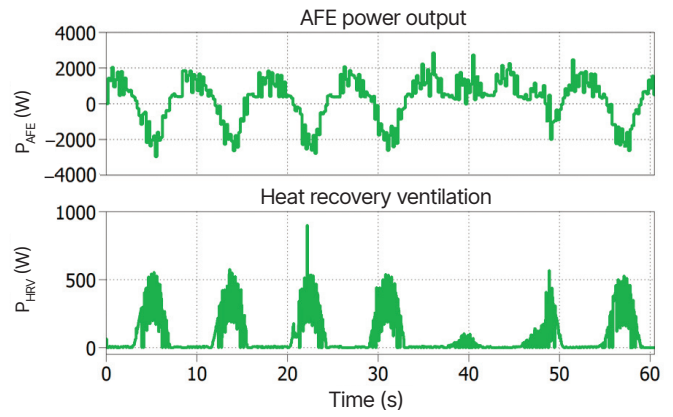


Fig. 11. HRV working in droop control.

consumes approximately 15 kWh per week, corresponding to about 10% of the total weekly PV production. Therefore, its impact on RSC is expected to be significantly smaller than that of the HP.

As in the HP case, the application of droop control reduced the maximum defrosting power from 900 W to 575 W. By appropriately adjusting the droop coefficient, the defrosting operation was shifted towards daytime hours, thereby improving its alignment with PV generation, as illustrated in Fig. 11. During nighttime hours, the defrosting power was effectively reduced to 0 W. However, the droop-controlled HRV had only a minor influence on the behaviour of the AFE converter. The maximum AFE power level, approximately 2 kW, remained unchanged (Fig. 11). Consequently, as expected, the increase in RSC was limited, reaching a value of 0.53.

5.4. Combined droop control of HP and HRV

The implementation of combined droop control does not inherently guarantee a maximum RSC value. As the number of controllable devices in a residential DC nanogrid increases, the coordination and tuning of droop coefficients become more complex. Adjusting the droop characteristic of one device inevitably influences the operation of other devices connected to the same DC bus.

In the present case, the application of combined droop control resulted in a slight reduction of the geothermal HP's peak power to approximately 1.5 kW, while the HRV peak power was limited to 527 W. The overall load behaviour remained similar to the individual control cases: both the HP and the HRV adjusted their power consumption in response to PV availability, increasing output during daytime hours and minimizing consumption at night, as shown in Fig. 12.

As a result, an RSC value of 0.69 was achieved, which is equal to the value obtained when only the HP was controlled. This result indicates that the selection and coordination of droop coefficients require further optimization to fully exploit the potential of combined load control. However, the flexibility of conventional linear droop characteristics is inherently limited. Any adjustment intended to increase the load power during periods of high PV generation may also increase the minimum power consumption during nighttime periods. Consequently, maximizing daytime consumption while simultaneously minimizing nighttime demand cannot always be achieved through linear droop characteristics alone. One

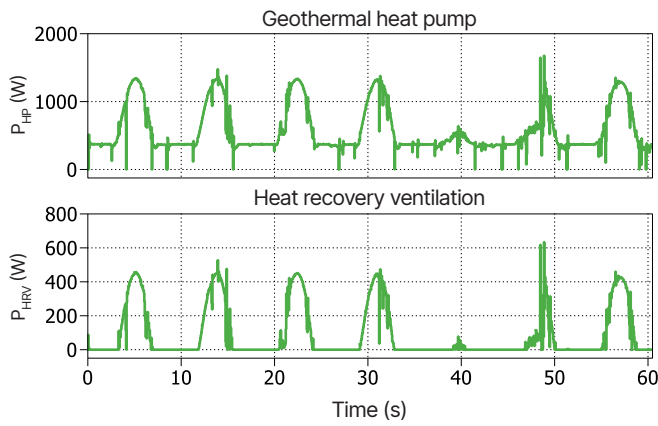


Fig. 12. Combined droop control of the HP and HRV.

potential solution is the implementation of nonlinear droop curves, which would provide greater flexibility in shaping the load response according to the available PV generation. The development and optimization of such nonlinear droop control strategies will therefore be considered in future work.

6. Conclusions

The simulation results demonstrate that intelligent load management can significantly enhance renewable self-consumption (RSC) in residential DC nanogrids without the need for local energy storage. Under baseline operating conditions, the household achieved an RSC of 0.51, with the geothermal heat pump and heat recovery ventilation (HRV) system as dominant controllable loads.

The application of droop control to the geothermal heat pump increased the RSC by 26%, reaching a value of 0.69. In contrast, implementing droop control for the HRV defrosting function successfully synchronized its operation with PV generation but resulted in only a marginal improvement in RSC, increasing it to 0.53. This outcome reflects the relatively small share of HRV defrosting energy in total household consumption.

The combined application of droop control to both loads did not yield the highest RSC value. The resulting RSC of 0.69 indicates that the interaction between multiple droop-controlled devices introduces additional complexity, and that the selection and coordination of droop coefficients require further optimization to fully exploit the potential of distributed load control strategies.

In general, the findings highlight the effectiveness of droop-based load control for enhancing renewable energy utilization in residential DC nanogrids, while also emphasizing the importance of systematic parameter tuning when multiple controllable loads are involved.

Data availability statement

All data are contained in the article.

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Taastuenergia omatarbimise suurendamine elamute alalisvoolu nanovõrkudes statismjuhtimise abil

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Artikkel uurib koormuste statismjuhtimist kui detsentraliseeritud strateegiat taastuenergia omatarbimise (*renewable self-consumption* – RSC) maksimeerimiseks elamu alalisvoolu nanovõrkudes ilma lokaalse energiasalvestita. Kuigi statismjuhtimist rakendatakse laialdaselt alalisvoolu mikrovõrkude energiaallikate ja akusalvestite haldamisel, on selle süstemaatilist kasutamist elamute koormusjuhtimiseks endiselt ebapiisavalt uuritud. Selles uuringus töötati tarkvara PLECS abil välja elamu alalisvoolu nanovõrgu mudel, kasutades seejuures Põhja-Eestis asuvas eramus reaalselt mõõdetud päikesepaneelide tootlikkust ja energiatarvet.

Koormuse statismjuhtimist rakendati maasoojuspumbale ja soojustagastusega ventilatsioonisüsteemi (*heat recovery ventilation* – HRV) sulatusfunktsioonile. Selleks et säilitada mudelis samaväärne nädalane energiatarbimine, rakendati energiapõhist kalibreerimismeetodit. Ühenädalase mõõtmisperioodi simulatsioonitulemused näitavad, et ilma statismjuhtimiseta saavutatakse RSC väärtus 0,51. Statismjuhtimise rakendamine maasoojuspumbale parandab RSC-d 26%, nihutades tarbimist päevasele ajale, mil on võimalik kasutada päikesepaneelide toodetud energiat. Seevastu HRV statismjuhtimine andis selle väiksema energiatarbimise osakaalu tõttu vaid marginaalse paranemise. Mõlema koormuse kombineeritud statismjuhtimine andis RSC väärtuseks 0,69. Tulemused näitavad, et koormuse statismjuhtimine võib oluliselt suurendada taastuenergia omatarbimist elamute alalisvoolu nanovõrkudes ilma akusalvestita.