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On-site energy generation in the manufacturing industry: effects on the variability of the net electricity demand

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Abstract: Local distribution system operators (DSOs) are currently dealing with the unpredictability and high variability of energy production coming from an increasing number of distributed variable renewable energy (VRE) systems. On the demand side, DSOs could count on the predictable electricity demand profile that characterises the manufacturing industry and effectively represents a baseload for the grid. The necessity to decrease the environmental impact of the industry sector is driving manufacturing facilities towards on-site renewable energy generation, affecting the predictability of the net demand profile. An on-site VRE system has been simulated for an existing manufacturing plant in Ireland to investigate the effects of on-site energy generation on the variability of the net demand. It is shown that on-site VRE generation increases not only the amplitude but also the occurrence of rapid fluctuations in the net demand during the year. The integration of a flexible technology such as a gas turbine for combined heat and power presents only limited benefits. Adding battery storage to the on-site system does improve the variability of the on-site integrated system but a high variability is still present. The manufacturing facility remains a net consumer in all the analysed cases.

1 Introduction

Until the last decade, most manufacturing facilities would satisfy their electric load by buying electricity from the grid. Nowadays, the significant cost reduction in variable renewable energy (VRE) technologies and the government effort at decarbonising the energy sector have made decentralised energy generation viable for energy consumers. An increasing number of residential, commercial and industrial energy consumers are now becoming also producers at a local level, producing distributed energy with decentralised systems located where the energy is needed, reducing transmission and distribution losses. While the effects of on-site energy generation have been analysed for the residential sector, the impact of a switch from the role of consumer to '*prosumer*' (consumer and producer) for manufacturing facilities has not been thoroughly investigated. The introduction of distributed energy generation would allow the facility to maximise the exploitation of available resources, avoiding energy waste and potentially reducing the environmental impact without interfering with the production processes [1]. However, by generating energy on-site, the almost constant and easily predictable electric load typical of manufacturing facilities could become more difficult to forecast.

This paper presents a statistical analysis of the hourly electric demand over an entire year of a specific manufacturing facility in Ireland. The simulated on-site energy system for decentralised energy generation is an integrated VRE system of solar photovoltaic (PV) and wind turbines: the renewable energy generated by the on-site system over one year is calculated and the new profile of the net demand, that the grid is required to cover, is shown.

The potential benefits of integrating the VRE system with a flexible technology such as a gas turbine (GT) for dispatchable power generation are investigated. Finally, the usage of battery storage is proposed and the effects on the variability of the net demand are presented.

2 Analysis of the hourly electricity demand profile of the manufacturing facility

The analysed Irish manufacturing facility has a 24/7 batch production process. Its hourly electricity demand for 2016, measured by an internal meter, is shown in Fig. 1. The average electric power consumption is 2660 kW while the maximum is just below 3500 kW. The demand profile is almost constant during the year without significant seasonal variations. There are four periods with an unusual trend caused by scheduled maintenance (July), reduced working shifts during holidays (December–January) and isolated errors in metering data (March); these periods are limited to 9 weeks.

The hourly ensemble average of a week relative to the average power demand is shown in Fig. 2. There is a diurnal variation on weekdays (Monday–Friday), while the demand on the weekend (Saturday–Sunday) has a flatter profile and a higher range of variation. Both the hourly trend and the range of variation (±5%) are comparable between weekdays, while the range of variation in the weekend is higher (±15%). The average electricity demand in the weekend is only 5% lower than the average consumption: this suggests that the diurnal variation during weekdays is not related to alterations in manufacturing processes, but reflects a reduction in secondary activities, such as back-office operations.

The electricity demand profile of the manufacturing facility significantly differs from a typical residential consumer due to the almost constant trend with relatively small diurnal, weekly and seasonal variations. Therefore, the commonly adopted strategies for demand-side management are not applicable in this case. In the next sections, the effects of on-site energy generation on the net demand profile are presented.

3 Scenario 1: On-site VRE system

Based on the hourly electric load of the considered Irish manufacturing facility, a solar PV and a wind system have been appropriately sized to limit overproduction of electricity to <1% of the time during the year: the installed capacity is 2000 kW_p for the PV and 2×900 kW_p for the wind system.

The electricity potentially produced by the VRE system has been simulated based on meteorological historical data and it is shown in Fig. 3 for every hour of a year.

The total energy required by the facility over the year is 23,296 MWh and the VRE produced on-site accounts for 5419 MWh (with only 17 MWh overproduced in 64 h). By introducing the VRE system on-site, the net demand that the grid has to satisfy becomes more variable, as shown in Fig. 4 there are higher fluctuations in the net demand which becomes more difficult to predict.

The weekly net demand profile changes significantly as shown in Fig. 5. The on-site VRE system creates a higher demand for grid electricity during nighttime and a drop around noon.

The range of variation of the electric net demand becomes wider as well. Fig. 6 shows that the standard deviation registered for the hourly net demand over each week of the year increases significantly compared to the case with no on-site generation (up to five times higher).

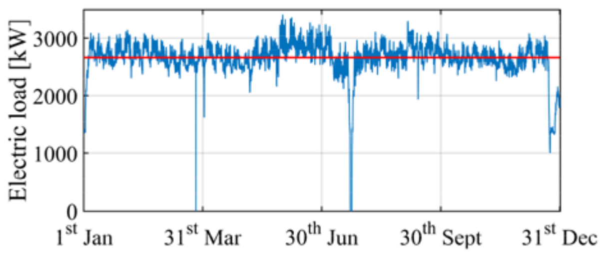

Fig. 1 *Electricity demand (average load highlighted)*

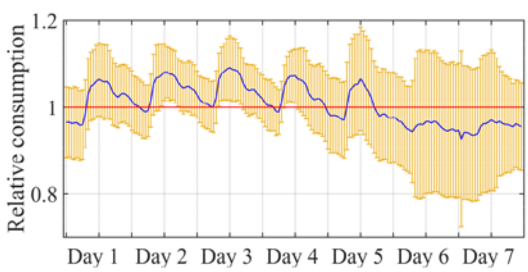

Fig. 2 *Ensemble average and error bounds over a week relative to the average consumption*

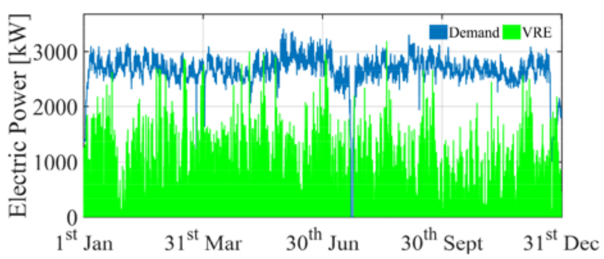

Fig. 3 *Electric demand and VRE generation*

4 Scenario 2: On-site VRE integrated with a GT cogeneration system

It has been shown that the introduction of a decentralised VRE system for self-consumption in a manufacturing facility has a strong effect on the variability of the net demand, substituting an easily predictable trend with a demand profile that is more variable and difficult to forecast due to the inherent uncertainty of the renewable sources exploited. The introduction of a flexible energy generation system could have the benefit of reducing the high variability of the net demand by absorbing, through its flexible operation, part of the fluctuations in the renewable sources availability.

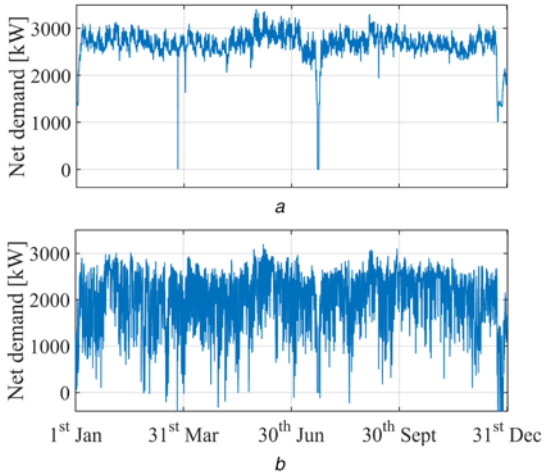

Fig. 4 *Net electric demand without and with on-site VRE*

a Without on-site generation
b With on-site generation

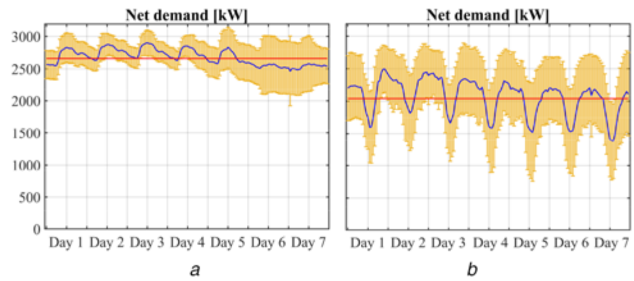

Fig. 5 *Weekly ensemble average and error bounds of electricity demand without and with on-site VRE*

a Without on-site generation
b With on-site generation

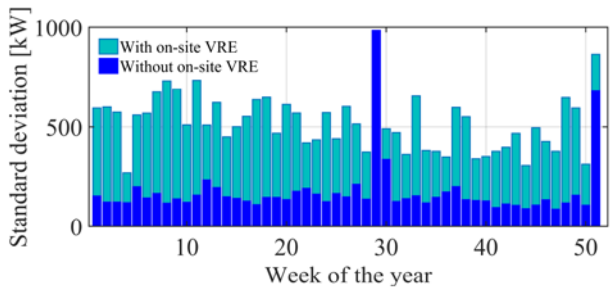

Fig. 6 *Weekly standard deviation of the net demand with and without on-site VRE*

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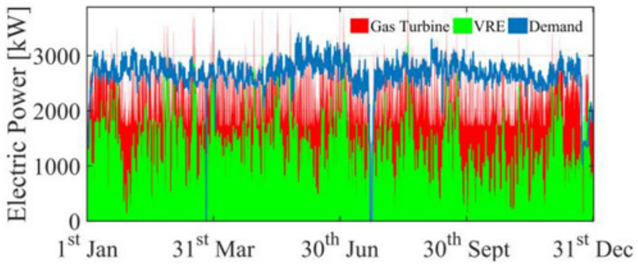

Fig. 7 *Electric demand and on-site electricity generation of the VRE and the GT systems*

Table 1 Electricity generation over one year by the VRE and GT on-site systems

MWh	Only VRE	VRE + GT
Grid electricity	17,894	4141
Electricity overproduced	17	236
Electricity from VRE	5419	5419
Electricity from GT	—	13,972

A particularly suitable option for on-site energy generation in the industrial sector is combined heat and power (CHP). On-site CHP technologies generate electricity and then use the waste heat produced to satisfy the heat load of the manufacturing facility. On-site cogeneration is a mature, reliable and economically viable option and with its flexible operation it could reduce the net demand variability; however, adding a CHP system will reduce the environmental benefits of on-site VRE.

The CHP system considered is composed of a GT, coupled with a heat recovery steam generator, to generate both the electricity and the high temperature/high flow-rate steam required in the production lines. Based on the net electricity demand of the facility resulting from the integration of the on-site VRE system (Fig. 4*b*) and on the models available on the market, a 1600 kW_{el} GT has been selected for the simulation of on-site electricity generation over 1 year.

The consumption of the electricity produced from renewables is prioritised to avoid the curtailment of fuel-free and low-carbon energy; the GT is then regulated in an electricity-following control strategy to avoid overproduction and minimise the grid electricity demand. The hourly production profiles of the VRE and GT system are shown in Fig. 7.

As detailed in Table 1, integrating the VRE system with the GT produces a significant reduction in the grid electricity demand but also an increase in the occurrence of overproduction (18% of the time during the analysed year).

The effect of on-site generation on the net load variability is assessed by calculating the standard deviation of the net load over a 5-h window spanning 2 h before and after every hour of the year [2]. The annual maintenance period (29 h in July) has been excluded from the calculations. In Fig. 8, the cumulative distribution function (CDF) of the variability is shown for the three analysed cases: no on-site generation, VRE only, integrated VRE and GT.

It is shown in Table 2 that introducing the GT into the on-site energy system decreases the maximum and mean variability of the net demand almost by 40% and increases the occurrence of a null variability to 7% of the time during the year (Fig. 8). However, the benefits of introducing a flexible GT are limited compared to the case with no on-site generation. The usage of battery storage is examined to reach a further reduction in the net demand fluctuations.

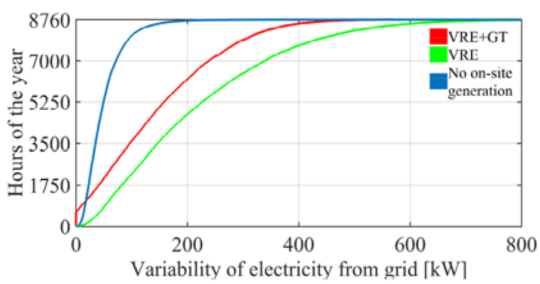

Fig. 8 *Cumulative distribution function of the net demand variability*

5 Scenario 3: Benefits of introducing battery storage

The potential reduction of the net demand variability through the introduction of on-site battery storage has been investigated. It is underlined that this analysis does not have the aim of optimising the overall integrated on-site system and its management but rather to investigate the effects of introducing a battery bank on the variability of the net demand. Different sizes have been considered and the simulation has been conducted with the software System Advisory Model (SAM) by NREL [3]. The range of battery bank size considered is between 1000 and 10,000 kWh, with a corresponding battery bank power between 200 and 1000 kW. The depth of discharge, the number of cycles performed and the progressive capacity degradation of the different battery banks are simulated; if the resulting lifetime of the storage system is shorter than 25 years a replacement is scheduled when the battery is not able to provide >80% of its original capacity.

Fig. 9 shows how the mean and standard deviation of the net demand variability change with the battery bank size: both the variables decrease with higher sizes, but no significant reduction is seen after the 5000 kWh battery bank. This is confirmed by the analysis of the CDF of the net demand variability displayed in Fig. 10, where only a small difference is registered in the CDF of the 5000 and 10,000 kWh battery banks. Hence, the additional cost of options bigger than 5000 kWh would not be justified, as shown by the progressively increasing of the PayBack Time of the battery system, due to higher investment costs and limited additional savings (Table 3). Over the year, the variability of the net demand is negligible 12% of the time with a 1000 kWh bank and 30% of the time with a 5000 kWh bank. The size optimisation of the on-site battery system is a trade-off between the PBT and the reduction in the net demand variability.

Table 2 Maximum, mean and standard deviation of the net demand variability

kW	No on-site gen	VRE	VRE + GT
Max	330	982	570
Mean	50	216	143
Std dev	43	151	109

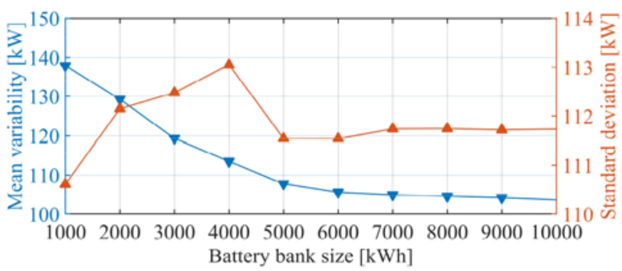

Fig. 9 *Mean and standard deviation of the net demand variability for different sizes of battery storage*

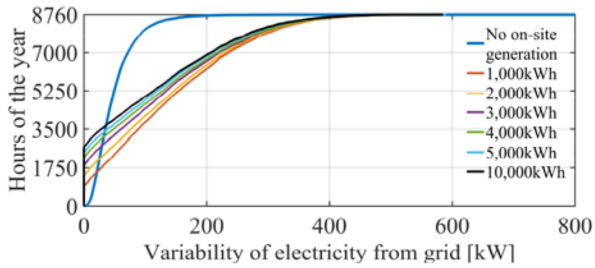

Fig. 10 *Cumulative distribution function of the net demand variability with on-site battery storage*

Table 3 Mean and standard deviation of net demand variability and PBT for the different bank sizes

Bank size, kWh – power, kW	Mean, kW	Std Dev, kW	PBT battery system, year
1000–200	137.8	110.6	1.3
2000–400	129.2	112.1	2.4
3000–600	119.2	112.4	3.4
4000–800	113.4	113	4.4
5000–1000	107.8	111.5	5.3
10,000–2000	103.6	111.7	10.3

6 Conclusion

It has been shown that the electricity demand typical of manufacturing facilities is almost constant during the year without significant seasonal variations and therefore effectively represents a predictable baseload for the grid.

The effects of introducing on-site generation have been quantified: the mean variability of the net demand, which has to be covered by the grid, rises from 50 kW in the original case with no on-site generation to 216 kW if a VRE system is introduced. The introduction of a flexible technology such as a GT for on-site cogeneration slightly improves the variability of the net demand (mean = 43 kW), but to reach a considerable reduction the system should be significantly oversized: this would entail higher investment costs and lower thermal efficiency of the GT working more often at partial loads (below the maximum efficiency load).

The usage of a battery system contributes to a further reduction of the variability but also in this case significant fluctuations occur during the year. The optimal bank size results from a trade-off between the PBT of the storage system and the reduction in the variability's mean and standard deviation. It is important to underline that even with the bigger storage system, the facility maintains the role of net consumer.

Future work could be done in studying the effects on the grid of a progressive transition towards decentralised energy generation of a cluster of manufacturing facilities, assessing the impact on the electric net demand and on the management of the electric grid.

7 Acknowledgments

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8 References

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