E3S Web of Conferences 45, 00037 (2018)
INFRAEKO 2018
https://doi.org/10.1051/e3sconf/20184500037

The use of photovoltaics and electric vehicles for electricity peak shaving in office buildings

Magdalena Krzywda[1,*], *Jakub* Jurasz[1] , and *Jerzy* Mikulik[1]

[1]AGH University, Faculty of Management, Department of Engineering Management, 30 Mickiewicza Ave., 30-059, Kraków, Poland

Abstract. The use of electric vehicles and photovoltaics is perceived as a viable option to reduce the human impact on the natural environment. This paper investigates the opportunity of managing a fleet of EVs along with PV installation in such a manner that shaves the peak load in an office building. The simulation used hourly load data representative for a small office building located in Cracow (Poland). For the same location hourly irradiation data was obtained. A deterministic model was created and implemented in MS Excel software. The study showed that 30 kW installed capacity in photovoltaics can reduce the observed peak load by 36% (from 19.8 kW to 14.52 kW) in a building consuming on an annual basis 54.7 MWh of electricity. Additionally, an appropriate management of the charging process of electric vehicles can increase the energy from photovoltaics self-consumption and level the observed energy demand in normal office building operating hours.

1 Introduction

It is a well-known and accepted fact that civilization is experiencing an increasing demand for energy. This is especially visible in the case of electricity which is the most "comfortable" energy carrier powering modern economy. In the near future this trend will most likely continue as there is a tendency to replace combustion cars with electric vehicles (EV). It is believed that they will reduce the transport sector impact on the environment but simultaneously will increase the demand for electricity. Current studies suggest that EVs are both a threat and an opportunity when it comes to power system operation and management. For example, A. Kies [1] showed that joint optimization of variable energy sources (wind and solar) with EVs can bring greater gains than their separate optimization. Dallinger and Wietschel [2] investigated the grid integration of variable renewable energy by using price-responsive plug-in EVs. Jacobson and Delucchi [3-4] showed that EVs can be used as an effective measure in renewable integration and achieving a 100% renewable based power system.

A specific case of an energy consumer is an office building (OB) which exhibits some typical daily and weekly energy demand patterns. These are driven by the building`s occupancy (usually from Monday to Friday and from 8:00 AM to 5:00 PM) and the need to

* Corresponding author: magda.krzywda01@gmail.com

maintain a comfortable working environment. Here, the thermal comfort which strongly impacts the office worker's performance and is maintained by energy consuming heating, ventilation and air-conditioning (HVAC) devices [5] is especially important. In OBs the energy demand is strongly impacted by the outdoor atmospheric conditions, especially air temperature and irradiation. Therefore OBs, usually with many glazed planes, tend to function as greenhouses and significant effort must be made to remove the excess heat by means of air-conditioning (AC). Here, a potential solution appears to reduce the AC driven power demand by applying photovoltaics (PVs) whose power generation positively correlates with the air-conditioning demand.

Considering the above, the objective of this study was to analyse whether EVs and PVs can be used to shave/level the observed peak load in an office building. The analysis focused entirely on energetic aspects and neglected the environmental and economic issues. The remainder of this paper is formulated as follows: Section 2 briefly introduces the data used and applied methods, Section 3 presents and discusses the obtained results and the paper ends with Section 4 which summarizes the findings and points out some potential future research directions.

2 Data and methods

As a case study, an office building (OB) (single floor rented by one company) located in the southern part of Cracow (Poland) was selected. The average energy consumption was around 160 kWh/m^2. The whole floor is divided into three smaller open spaces, each with glazed walls facing south (direct impact of the solar radiation). The office is equipped with standard comfort maintaining infrastructure in the form of HVAC devices. Further details cannot be disclosed due to reasons of confidentiality.

2.1 Photovoltaics potential

The PVs potential in terms of installed capacity has been estimated based on an aerial image of the building. As potential areas suitable for PVs installation we have considered an OB's roof and parking area. Our calculations show that it is possible to install up to 40 kW in PVs inn both areas and 30 kW if only the parking area is considered.

2.2 Load and irradiation

In our analysis we have used hourly data for power demand, irradiation and air temperature covering the whole year of 2017. The load was obtained from on-site measurements and both atmospheric parameters were downloaded from (http://www.soda-pro.com/) which shows a good fit with on-ground measurements [6].

Figure 1 visualizes the normalized weekly power demand pattern in the considered office building. Clearly the highest demand is observed during work days (Monday-Friday).

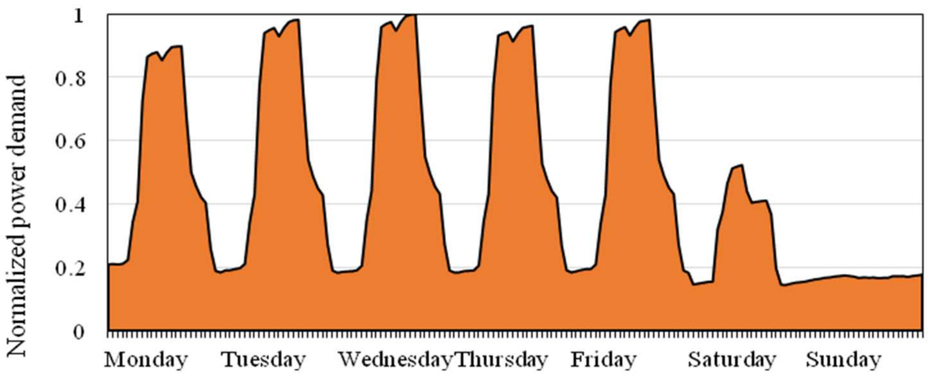

Fig. 1. Typical weekly, normalized, hourly load profile of the considered office building.

As shown in Figure 2, the energy demand varies not only on a weekly/daily time scale but also from month to month. The highest energy demand is observed in July and August when there is significant demand for air-conditioning. Fortunately, these are also the months where the highest sums of solar irradiation are observed – which translates almost linearly into the electrical energy delivered by PVs. The energy consumption in the considered OB amounted to 54.7 MWh per year.

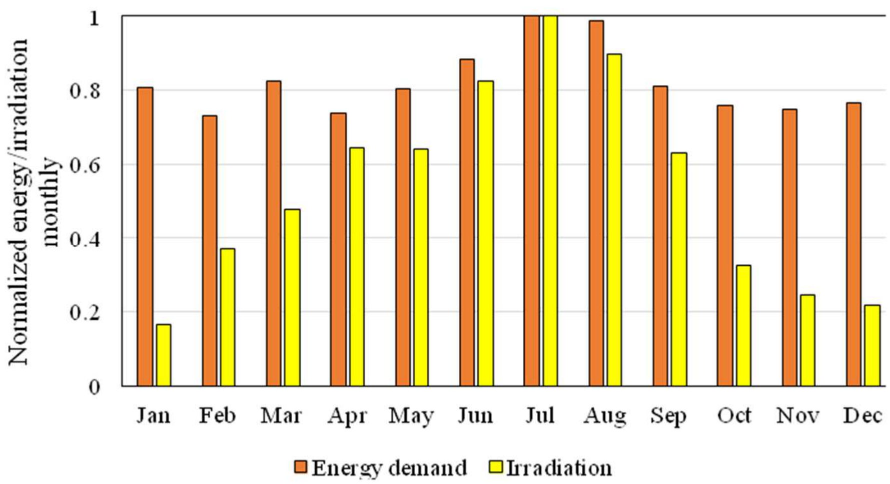

Fig. 2. Monthly, normalized sum of irradiation and energy demand in the considered office building.

2.3 Energy yield from PVs

The energy yield from PVs has been calculated based on a formula which takes into account the impact of module operating temperature on the efficiency, used *inter alia* by [7]. In the given location, 1 kW installed capacity in PVs will deliver around 986 kWh of electricity per annum, which translates into a capacity factor equal to 11.2%.

2.4 Peak shaving method

In our analysis we made the following assumption. The EVs arrive at the OB parking area (at 8:00 AM) and need to be charged by the end of the work day (17:00 PM) which gives a time window of 9 hours for charging. Each EV requires 10 kWh of energy. The storage capacity of EVs is irrelevant as they cannot supply power to the building. The maximal charging capacity of each EV is 40 kW. The standard procedure is to charge the EVs using even power during the entire charge time, meaning if the energy demand was 90 kWh (9 EVs each requiring 10 kWh) then the added load was 10 kW during each one of 9 charging hours. In the modified approach to EVs, the charging power is modified in such a manner that the overall load (OB plus EVs charging) remains at a constant level. Here a deterministic model was applied which assumes that the OB's energy demand as well as power available from PVs is known with 100% accuracy for the next 9 hours.

3 Results and discussion

3.1 Photovoltaics impact on load profile

The first part of our analysis focused on analysing how a PV installation will impact the observed load and energy demand in the OB. No energy storage has been considered, therefore the mismatch between supply and demand results in a decrease in energy from the PVs self-consumption. The results of our simulations are presented in Figure 3. As can be observed, on average each 1 kW capacity installed in PVs reduces the observed peak load by 0.16 kW. Additionally, installing 30 kW in PVs will decrease the energy bought from the grid by almost 42%. The beneficial load profile of the OB results in a relatively high self-consumption, in the case of 30 kW installed in PVs over 75% of generated energy is consumed by the OB. Naturally, adding capacity to PVs does not have a linear impact on the observed energy demand reduction and peak load.

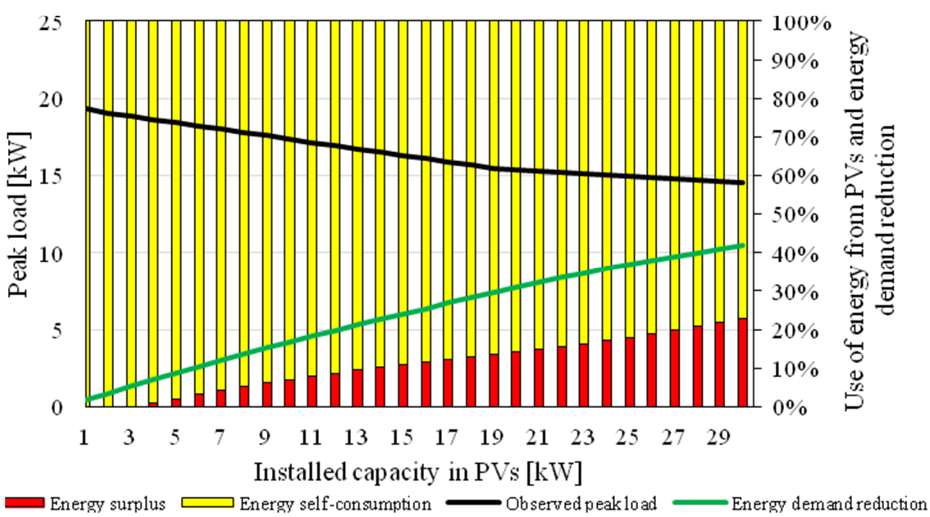

Fig. 3. Photovoltaics potential to reduce observed peak load and overall energy demand.

Despite reducing the overall energy demand (energy bought from the grid) / increasing the energetic self-sufficiency of the OB, the PVs supply profile significantly modifies the typical weekly load profile. Those changes are visualized in Figure 4 for four various capacities installed in PVs. As can be seen, the peak supply from PVs during midday results in increasing the variability of power demand during OB operating hours. Additionally, during midday on the weekends (especially Sundays) the observed load can be as low as 0 kW. This suggests that some energy storage may be beneficial as the energy surplus generated during weekends could be used during work days.

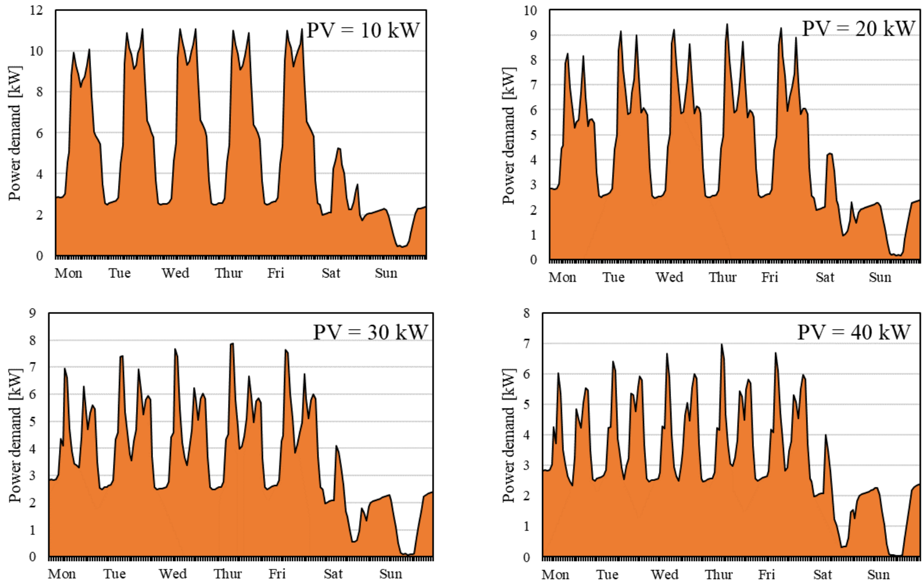

Fig. 4. Photovoltaics impact on typical weekly load profile depending on the installed capacity.

3.2 Adding EVs to the OB load

In the analysis we have considered two scenarios when it comes to EVs. In the first one the fleet of arriving EVs consists of 20 vehicles, and in the second it is twice as high and equal to 40 vehicles. Adding 20 EVs to the OB energy demand almost doubles it on an annual scale (an additional 52 MWh are needed to charge all EVs). As can be seen on Figure 5, in the normal charging mode there is a significant increase in the observed load. In the case of 40 EVs the observed typical peak load can be as high as almost 52 kW. However, a significant reduction in peak load can be achieved by adjusting the charging power accordingly to the supply from the PVs and OB load. In all four considered cases (Figure 5) it was possible to reduce the observed peak load as well as maintain it at the same level during the building`s operational hours. Naturally, those results were obtained for a deterministic model, and some potential operational errors will be observed in the case of real operation (uncertainty in case of PVs supply and OB load).

Applying a charging strategy for EVs not only reduces the peak load and levels the power demand, but also increases the energy self-consumption from PVs. EVs are capable of using energy surpluses (supply from PVs greater than OB demand). It was found that EVs can increase the energy self-consumption up to 90% which is very beneficial, as selling energy surpluses to the grid or storing them is not always economically justified.

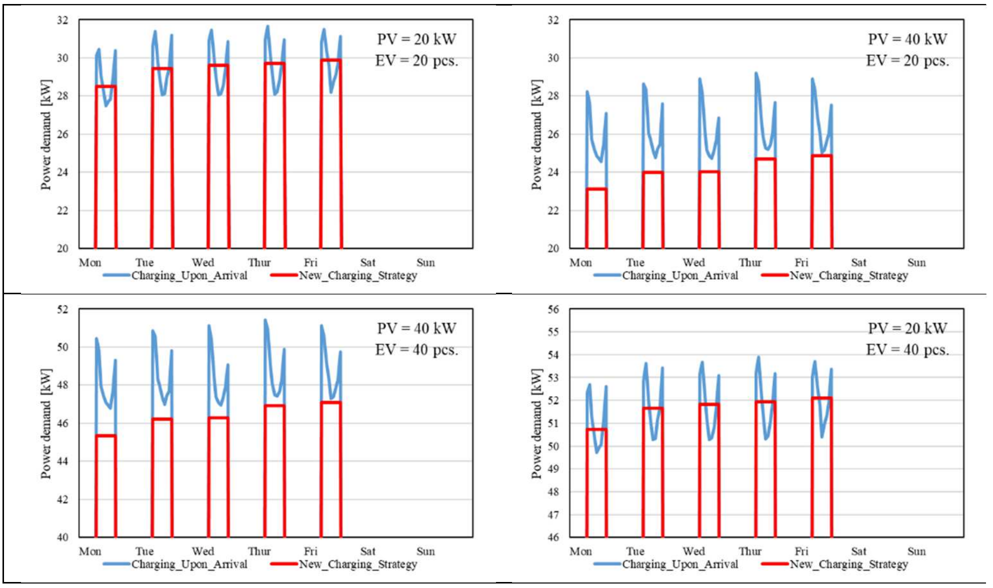

Fig. 5. Various configurations of installed capacity in PVs and the number of EVs impact on typical daily peak load under a conventional and modified charging strategy.

4 Conclusions

The conducted calculations and analysis enables us to formulate the following conclusions:

- considering the high air temperature and irradiation impact on the OB load profile as well as its repeatable daily profile, PVs as an energy source has huge potential to reduce the observed peak load; however, energy storage may be crucial to limit the energy flow between a building and the grid,
- EVs will undoubtedly increase the overall energy demand as well as the observed peak load; however, as they are to some extent a dispatchable load this poses a significant potential to shift and level the observed load values,
- the appropriate management of charging process for EVs can simultaneously reduce the peak load as well as increase the self-consumption of energy coming from PVs;
- a hybridization of energy source (by adding for example a wind turbine [8, 9]) should be considered to increase the system reliability.

Considering the above, future research should concentrate on the following aspects of using EVs and PVs in peak load shaving/load levelling:

- probabilistic model, which considers the inaccuracy of the energy yield of PVs and load forecasts should be developed to validate the proposed peak load shaving/levelling concept,
- economical aspects of peak shaving/levelling by means of EVs and PVs should be analysed and threshold of a cost-effective installed capacity in PVs in the current market situation established.

References

1. A. Kies, J Phys Conf Ser **977**(1), 012005 (2018)
2. D. Dallinger, D., M. Wietschel, Renew Sust Energ Rev, **16**(5), 3370-338 (2012)

3. M. Z. Jacobson, M. A. Delucchi, Energ Policy, **39**(3), 1154-1169 (2011)
4. M. A. Delucchi, M. Z. Jacobson, M. Z. Energ Policy, **39**(3), 1170-1190 (2011)
5. G. Augustyn, J. Jurasz, K. Jurczyk, T. Korbiel, J. Mikulik M. Pawlik, R. Rumin, E3S Web Conf **22**, 00004 (2017)
6. J. Jurasz, M. Wdowikowski, B. Kaźmierczak, P. Dąbek, E3S Web Conf **22**, 00074 (2017)
7. B. François, B. Hingray, M. Borga, D. Zoccatelli, C. Brown, J. D. Creutin, Energies, **11**(2), 290 (2018)
8. B. Ceran, E3S Web Conf **22**, 00028 (2017)
9. R. Szczerbowski, B. Ceran, In E3S Web Conf **10**, 00090 (2016)