EVALUATING ELECTRICITY SELF-CONSUMPTION IN DIFFERENT RENEWABLE ENERGY SUPPLY CONDITIONS

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Abstract. The aim of this article is to detect energy storage problems in dwelling buildings with PV panels and wind generator based electrical energy supply. The focus of the research is to maximise the yield of energy consumed on-site utilising two water heater boilers with equal volumes as energy storage devices and consumption in household devices as white goods, lighting, etc. Energy output from fluctuating sources like PV panels and wind generators is divided by a desired horizontal shaving level on the production curve, separating peaks and stable production. Energy peaks are fed to a pre-heating water boiler and the main part of energy below the shaving level is used in the main boiler and consumption of household devices, maintaining the equalised balance of produced and utilised energy. The observational period is one year with 5-minute averaged data points. Wind generator energy output is calculated according to three different wind conditions, evaluating self-consumption, while retaining PV panel yield on the same level. The produced solar and wind energy ratio is 30 %/70 %. The compared wind conditions result in a capacity factor of 0.055 in the worst case and up to 0.273 in better conditions, while the cover factor increased from 0.6 up to 0.68. If the energy demand is the same, the needed rated capacity of the wind generator can be 5 times smaller in the best conditions.

Keywords: wind energy, solar energy, peak shaving, cover factor, demand response.

Introduction

Utilisation of solar and wind power has one of the longest historical backgrounds among renewable energy sources. The technological advancement has been in steep ascension during the last decade as modern large scale high output solar and wind power plants are demanding focused research and development on equipment [1]. Rapid developments on the field of small-scale PV and wind technologies have had strong support from the EU legislation that is also related to net zero-energy buildings [2; 3]. It is a known fact that wind turbine and PV panel output is fluctuating and almost non-predictable [4]. To smooth out the output of these primal energy sources, local demand side management (DSM) methods are applied. The most common are different heat-pump-based technologies [5; 6], although chemical batteries [7; 8], pumped-storage hydroelectricity [9; 10], DC loads [11], solar and wind forecast [12], compressed air storage [13] and micro-grid systems [14] are also in use. Another solution to relieve power stochasticity is to store the short peaks of electrical energy production in an additional pre heated water boiler as heat energy [15; 16] and at the same time utilising load shedding and power shifting technologies. This approach allows to store short-lasting energy peaks above the set shaving level without DC/AC alternation allowing smaller inverters with stable output. In the current study, the shaving level is from zero to 100 %, where 0 % is a state, where all the energy is diverted into the pre-heating boiler and 100 % means that no power shaving is exploited.

The aim of this study is to evaluate possibilities to increase the self-consumption share under different wind conditions by using production curve peak shaving methods to dividing energy flows to two branches. For energy storage we use two equal volume boilers.

Materials and methods

The wind generator used for the modelling and simulation of the parameters is the following: it has a rated power of 10 kW, located in a coastal area (N 59.087694, E 23.591719) and it is produced by TUGE Ltd [16]. The 10 photovoltaic panels have a total rated power of 2.5 kW, located in an urban area (N 58.388458, E 26.694000) and the producer is DelSolar [16]. The measured period covers a time beginning with the 1st of December 2015 and ending with the 30th of November 2016. The year is divided into four periods as follows: winter – December to February, spring – March to May, summer – June to August, autumn – September to November. The production curve is shaved at 5 minute average power levels, whereas the succeeding calculations are based on the corresponding energy portions. The solution for energy storing (Fig. 1) consists of two equal size boilers: a water pre-heating tank (WPHT) with two separate electrical heating elements and the main boiler. The WPHT acts as a

dump load system for the shaved power peaks, allowing the utilising of both: AC and DC power from the wind generator and from the PV panels due to separate heaters. The system is equipped with an emergency pressure relieve valve that can dump excess hot water into the drainage. The main boiler is designed to consume all of its energy demand below the shaving level, and is equipped with two separate heaters. Both boilers must be able to work separately, because a 0 % shaving level means 100 % utilisation of the pre-heating boiler and vice versa – 100 % shaving level leaves the entire load to the main unit.
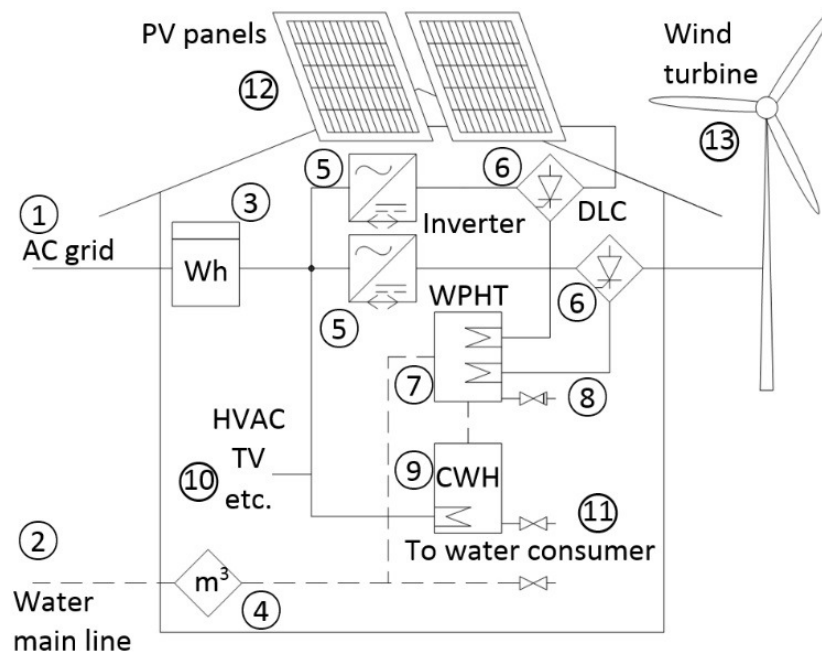

Fig. 1. **Scheme of proposed systems:** 1 – AC grid connection; 2 – cold water main line; 3 – two way electrical energy meter; 4 – water meter; 5 – inverters for solar panels and wind generator; 6 – dump load controllers (DLC) for solar panels and wind generator; 7 – water preheating tank (WPHT) with two separate heating elements; 8 – safety pressure release valve; 9 – conventional water heating tank (CWH); 10 – non-shiftable loads; 11 – Hot water output; 12 – PV panels; 13 – wind generator

The current research uses a typical household power demand curve consisting only of non-shiftable loads like white goods etc. and a water heating boiler system. Power demand is measured during a two week period and adjusted for the whole year as consuming habits of people do not change notably [18; 19]. Electrical energy demand during the given period was 3473 kWh per year, which is a value between the Estonian and European Union average values (2957 kWh per year vs 3601 kWh per year) [19; 16]. The PV panels' and wind generator production curves are similar as given in [17]. Although, the daily average energy used for hot water production is 5.05 ±1.80 kWh [22].. The maximum energy capacity calculated in this case per day of a commercially available 80 l boiler is 5.4 kWh [16].

The annual energy yield of the wind generator and PV system are scaled to be 70 %/30 % [20] in favour of the wind energy [18; 21]. The model for evaluation of the self-consumption is tested with capacity factors (*CF*) of wind generators ranging from 0.051 to 0.28, at the same time the capacity factor of solar panels *CF* = 0.11 [16] is constant. We analyse the dependence of rated power according to *CF* (Fig, 2.) visualising the necessary nominal power output change in different wind conditions.

The essence of *CF* is the ratio of actually produced energy in relation to the theoretically possible energy production during some time period (commonly one year, *T* = 8760 h).

$$CF = \frac{W}{P_r \cdot t},$$

(1)

where W – really produced energy in certain period, e.g. one year;
          P_r – rated power of production device;
          t – time period (in this case 8760 h).

Fig. 2 depicts that the relation of the necessary nominal output power of the wind generator to generate the same energy amount is not linear, there is a steep rising slope at *CF* values lower than 0.15.

As the production is equal to the usage, then the cover factors are also equal $Y_S = Y_D$, so hereafter we discuss only *Y*, representing the supply cover factor Y_S.
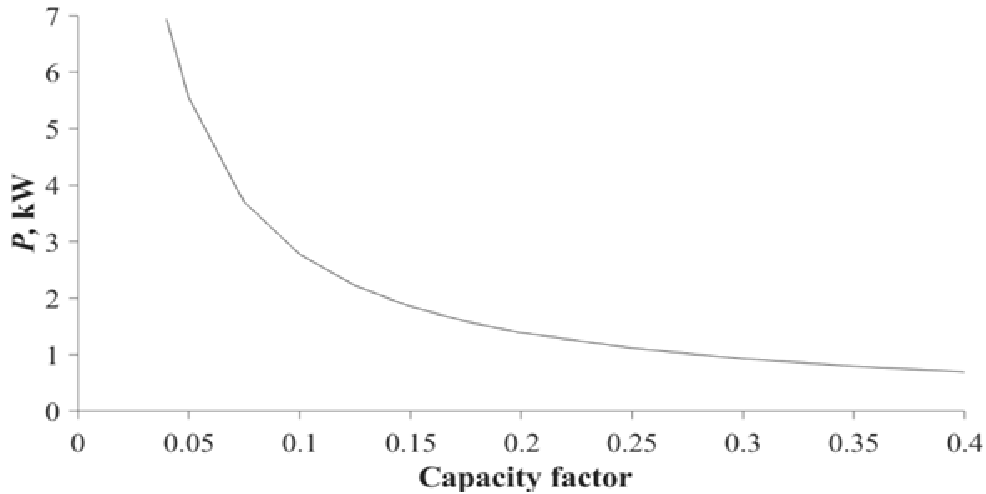

Fig. 2. **Wind generator output power according to capacity factor**

The cover factors $Y_S = Y_D$ [22; 23] express both locally produced and directly consumed power shares:

$$Y_s(t_o...t_2) = \frac{\int_{t_0}^{t_1} P_D dt + \int_{t_1}^{t_2} P_S dt}{\int_{t_0}^{t_2} P_S dt}, Y_D(t_o...t_2) = \frac{\int_{t_0}^{t_1} P_D dt + \int_{t_1}^{t_2} P_S dt}{\int_{t_0}^{t_2} P_D dt}, \tag{2}$$

where P_S – local power supply;
        P_D – local power demand.

The time, when $P_D(t) \leq P_S(t)$, is denoted as $t_0...t_1$, and $t_1...t_2$ is the time, when $P_D(t) > P_S(t)$. The supply cover factor is a measure for the self-consumption of locally produced renewable energy [6]. Similarly, the demand cover factor is defined as "the ratio to which the energy demand is covered by the local supply" and indicates the "self-generation" [6].

Nevertheless, energy stored into hot water but diverted to drainage is not included into calculation of *Y* as energy use. In cases, where the production curve depths of peak shaving levels (*DPS*) are at levels of 20-30 %, the loss is notably increasing as shown in Figure 4. The use of a maximum value of the *CF* is not feasible, as the losses are also at highest. Energy loss from the boiler is calculated to be 10 % of the whole energy stored, being 184 kWh per year [24]. Yet the heat energy lost through the boiler thermal insulation accounted as the heat source for building thus lowering the energy used for general heating.

Results and discussion

Fig. 3 illustrates the cover factor relations to *DPS* as *Y* maximums are shifting left, while *CF* values are lower, while higher *CF* values are resulting from higher peaks. Minimum *Y* values are in all cases 0.27, while all the energy is diverted through the pre-heating boiler. The maximum *Y* value of 0.7 is achieved only with the best wind conditions available.

Energy losses due to occasions when the preheating tank is overheating are depending on the *DPS* level and the *CF* value that Fig. 4 illustrates and all calculations were done considering the energy amount per boiler 5.4 kWh. Because it is difficult to determine an even temperature in a volume boiler, it was not used as an indicator. The emergency release valve works according to pressure. There are energy losses in the case of three different *CF* values, being the smallest around a cutting

limit of 20 %, while CF=0.055. In other cases, the inclination of the curve is less steep, although wasted energy turns to zero in all cases on a shaving depth of 60 %.
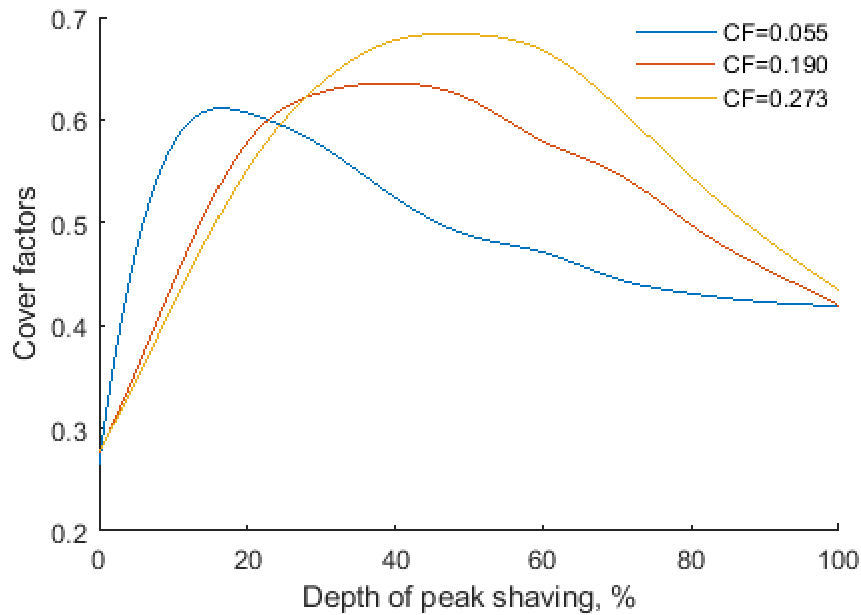

Fig. 3. **Dependences of cover factor and peak shaving levels on different capacity factors**
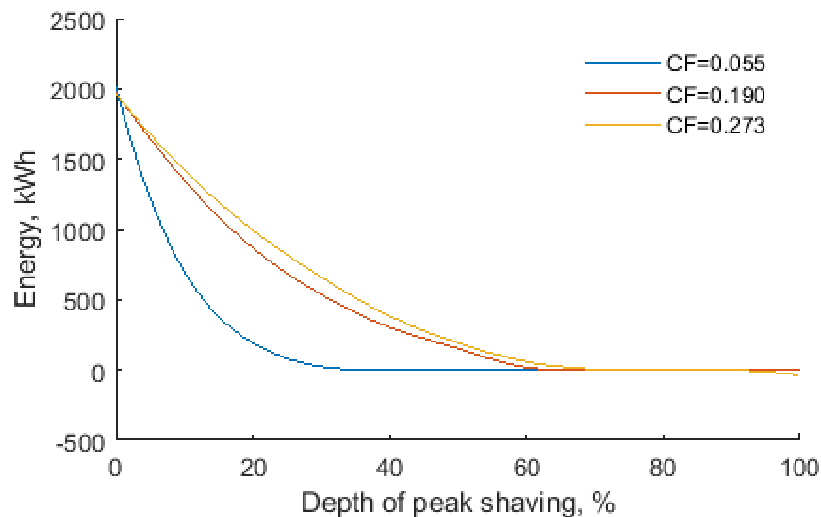

Fig.4. **Wasted energy according to depth of peak (DPS) shaving levels on different capacity factors (CF)**

Table 1

Results modelling by different wind CF´s

CF (PV)	CF (wind)	DPS, %	Y	P_r, kW
0.11	0.055	20	0.6	5.05
0.11	0.190	47	0.63	1.46
0.11	0.273	50	0.68	1.02

Taking for granted the 10 % criteria, the losses are less than 184 ± 10 %. Counted this condition, the results are presented in Table 1. The data are taken from three different CF levels, which means three different wind conditions. To get a certain energy amount during the year, that is the same in all cases, but in different wind conditions, the necessary rated capacities P_r of the wind generators certainly are different. The difference of the rated powers for the wind generators are nearly up to 5 times.

Thereof it could be concluded that better wind conditions allow increasing the locally consumed energy percentage and usage of a smaller size wind generator, thus shortening the payback period of energy production devices. Although the increase is not drastic (8 %), then an additional effect comes from a smaller wind generator in better wind conditions.

Conclusions

1. The novelty of this research is the determination of the influence on different CF to Y by using production curve peak shaving to increase the self-consumption. The proposed system used two same size boilers, the energy from the peaks is directed to one and the energy under the shaving line is directed to the other.
2. Better wind conditions allow increasing the renewable energy proportion in a dwelling, in this research the CF values were varying in a range of 0.055 to 0.273, and the resulting Y values were changing from 0.6 to 0.68. At the same time it is possible to scale down the wind generator's rated power up to 5 times, which gives significant economic effect by decreasing expenses to energy production devices.
3. The proposed solution is relatively cheap, because the additional boiler cost is marginal and inverters need only configurational changes concerning the dump load activation value.

Acknowledgements

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