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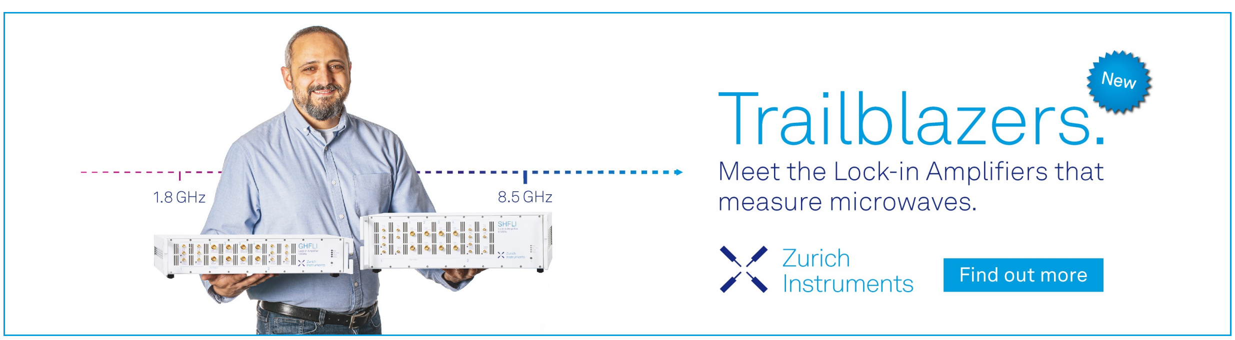

Replacement of Solid Fuel Power Generating Capacities by Photovoltaic Power

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Abstract. This report analyses the possibilities for replacing solid fuel power plants by photovoltaic power plants. The analysis is based on annual and monthly electricity production. The nature of the annual load profile of the replaced and replacement capacities, the availability of electricity storage capacity and some issues related to the centralized, and decentralized deployment of the replacement capacities are considered.

INTRODUCTION

In Republic of Bulgaria, as well as in many countries, a major part of electricity production is currently carried out on the basis of generating capacity, using for primary energy the thermal energy that is released during coal combustion. As known, this process of energy recovery from coal is accompanied by the release of significant amounts of carbon dioxide, dust particles and other types of gaseous pollutants. In addition, coal mining itself, which is mainly carried out in open-cast mines, is directly linked to environmental disturbance, soil, air and water pollution, and requires reclamation of the soil and areas in which it takes place. Also, the production of electricity by this method is associated with the payment of CO_2 allowances, which significantly increases the price of electricity produced. These facts, as well as the strategies for achieving carbon neutrality of electricity generation, require the search for options for generations using other types of technologies and primary sources. The main requirements to the sought capacity to replace the current production are that it is environmentally friendly and allows consumers to be supplied with the necessary electricity at any time of the day [1]. In this aspect, the possibility of replacing centralized „CO_2 – generating" capacities with centrally and decentrally located Photovoltaic Power Plants (PVPP) is of interest.

The issue of centralized and decentralized allocation of generating capacity is essential, because in a centralized allocation, these capacities are usually located remotely from the main consumers and settlements. This leads to an increased number of voltage transformations, to the use of long power lines, and to higher losses of active energy. Decentralized location (local installations at or near the consumer) avoids some of the mentioned shortcomings, but it in turn is associated with more complex management of the distribution of electricity to its consumers and control of its production in the course of time.

From the point of view of centralized capacity, the replacement of generating capacity using coal from open-cast mines seems to be easily solvable in terms of territorial availability. For example, the territory of the Maritza Complex, used for coal mining and electricity generation, has an area of about 240 km2. This area implies sufficient

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availability of space that the current capacity can be replaced by a PVPP in the same area. But here is the question how they should be replaced – on the basis of power or by quantity of electricity generated.

On the other hand, the development of electricity generation systems from renewable energy sources allows them to be built at the consumers themselves, including single-family users, which reduces the electricity costs of consumers in the long run and increases their energy independence.

ANALYSES OF THE POSSIBILITIES FOR REPLACEMENT OF COAL GENERATING CAPACITIES BY PHOTOVOLTAIC CAPACITIES

In the analysis performed in this study, in order to compare the results, all data used are reduced to a unit of installed power according to the dependence:

$$reduced\ value,\frac{kWh}{1kW(\mathrm{X}kWp)}=\frac{amount\ of\ \ electricity, kWh}{installed\ net\ power, kW(kWp)} \tag{1}$$

which installed power for coal generation is 1kW, and for photovoltaic power is XkWp, where X is in accordance with the conditions described below.

TABLE 1. Produced electricity kWh for 1kW installed power

	2017	2018	2019	**Average**	**Max**
January	603	336	608	516	608
February	488	266	528	427	528
March	339	294	530	388	530
Aril	406	80	486	324	486
May	517	275	323	372	517
June	342	290	60	230	342
July	346	417	440	401	440
August	441	454	594	496	594
September	388	591	526	502	591
October	552	582	635	590	635
November	560	616	625	600	625
December	447	644	544	545	644
Total:	5428	4844	5901	5391	6542

Table 1 presents the quantity of electricity produced for 2017, 2018, and 2019 by a single power unit using coal, reduced to the net power of generators. The Max column shows the maximum value out of the monthly values from the three years.

The electricity generated by the photovoltaic systems is calculated by [2][3] on the basis of average annual solar radiation, determined for geographical location of Stara Zagora and Haskovo districts, at a slope of 30°, without solar monitoring systems, and density of generating capacities of photovoltaic panels 193,08 Wp/m2. The data attached to the analysis below is for the amount of electricity from the PVPP at the point of delivery and taking into account the losses in the PVPP.

As a basis for the analysis of what photovoltaic power (PVP), X kWp should replace 1kW of coal power (CP), the following three options are studied:

1. 1kW CP to be replaced directly by 1kWp photovoltaic power, see fig. 1. It can be seen that in this case we will have insufficient annual electricity produced by PVP.

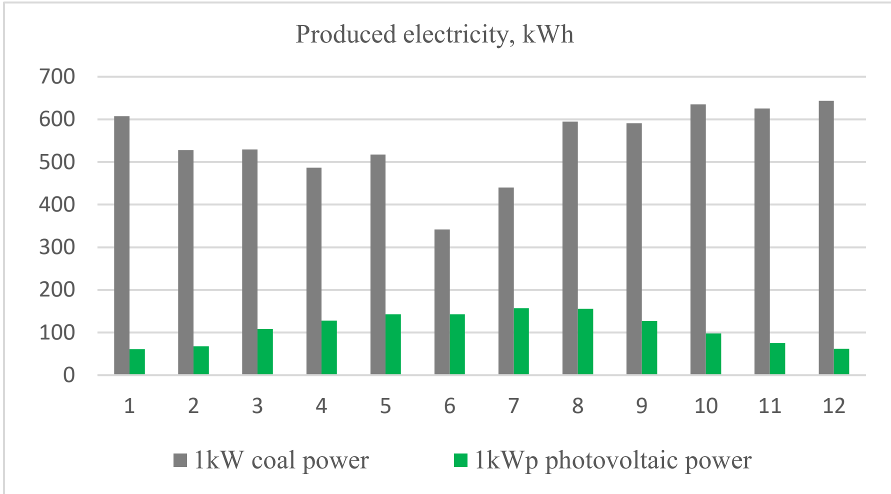

FIGURE 1. Monthly electricity production with equal installed net capacities

2. 1kW CP to be replaced by such quantity of PVP, so that we have the same amount of produced electricity, as according to the real load profile of CP. However, here we have several options on which or what load profile to use as a base - load profile for a specific year (Table 1, year 2019, Wh/year = Max), the average load profile by months for the above three-year periods (Table 1, column Average) or that of the maximum monthly productions (Table 1, column Max). In the case of fig. 2, as in fig. 1 and fig. 3, it was chosen to make the comparison with the maximum monthly loads (Table 1, column Max) in order to have a better provision of the possible maximum loads.

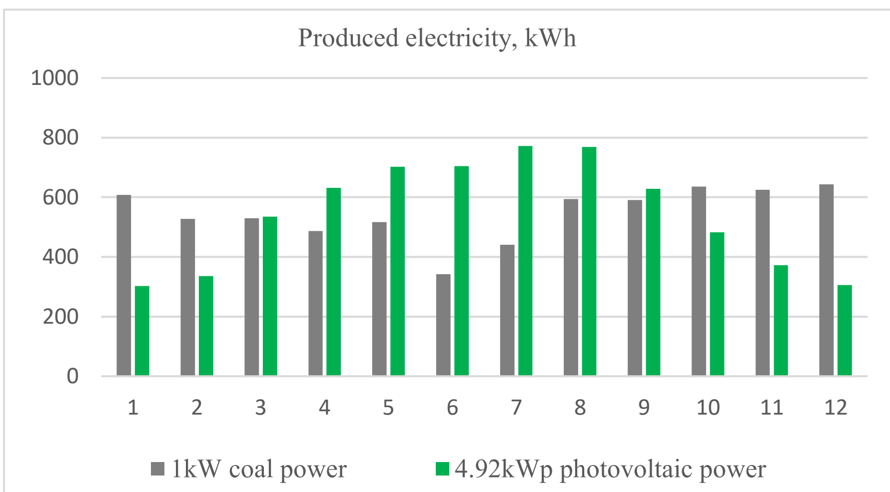

FIGURE 2. Monthly production with equal amounts of electricity per year from CP and PVP

According to the results, in order to achieve equal annual quantities of electricity, 4.92 kWp PVP should be installed to replace 1kW CP.

3. If we look at fig. 2, although we have equal annual production of electricity from both types of capacity, it is obvious that photovoltaic production does not cover during the coldest months, i.e. of winter. From here, we get the third main (at first glance) option, i.e. the photovoltaic power to be such that there is no "uncovered" by it monthly production versus CP. The calculations show that for the considered case this will be achieved if 10.36 kWp PVP are installed per 1kW CP, as the base month turns out to be December. In this case, however, the total annual production of PVP exceeds that of CP 2.10 times, and in the summer months we have more than 3 times the production of CP. Furthermore, with respect to item 2 (fig. 2) we have 2.10 times more installed PVP.

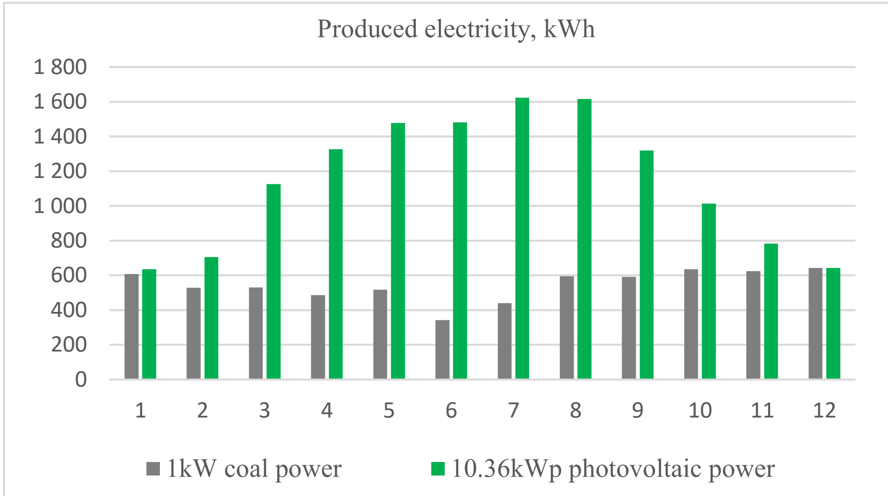

FIGURE 3. Monthly electricity production in the case of PVP generation is not less that of CP

From fig. 3 it can be seen that in summer power will be generated, which will most likely be about 3 - 5 times greater than the transmission capacity of the network. This raises the question of how to store or use this energy, whether at the place of its production or it will be more profitable to increase the transmission capacity of the network, or part of the PVP to be located decentrally at consumers, or simply not to be generated, but its price to be included in the price of the sold energy. In turn, in the decentralized construction of PVP, each consumer could assume the role of an investor, to determine for himself or in a partnership the necessary PVP and means for energy storage.

From the results related to fig. 1, fig. 2 and fig. 3, it is evident that in general, the optimal decision in terms of electricity (without the financial part) regarding the question of what PVP to replace the CP, lies between the options of item 2 and item 3. These options can be considered as marginal, provided that they also take into account the losses of electricity related to storage and secondary supply. Storage, on the other hand, requires an analysis of how much electricity will need to be stored.

The analysis of the required amount of electricity for storage could be made on the basis of average daily or maximum 24-hour load profiles for each month or week on the basis of statistical data or forecast methodologies.

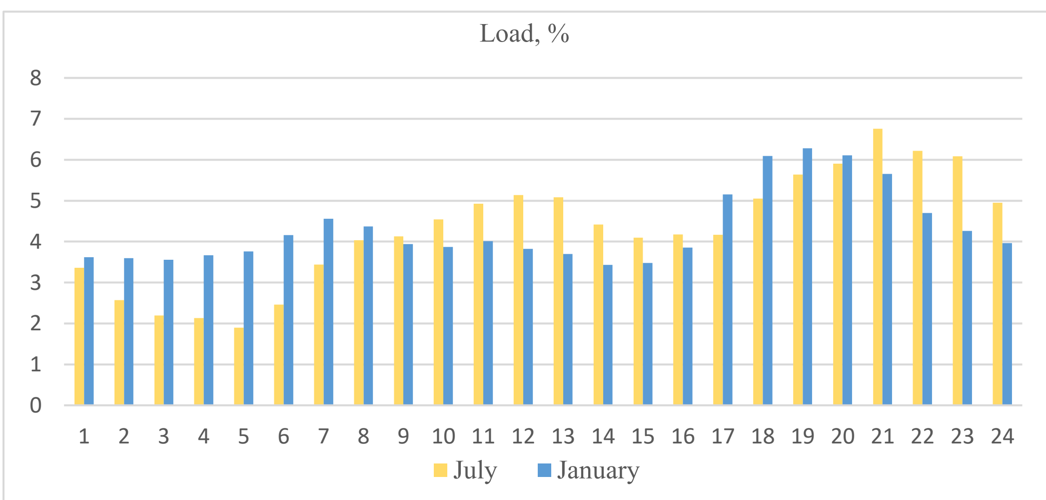

FIGURE 4. Estimated hourly distribution of household loads, administration and street lighting in a settlement for one day, expressed as a percentage of the total daily load (forecast methodology [4][5])

Fig. 4 shows in percentage terms the daily estimated distribution [4][5] of the loads by households, administrative buildings and street lighting in one settlement for the months of July and January, typical for the seasons of summer and winter. The calculations show that in summer the loads in the dark hours of the day are about 42%, and in winter they reach 69% of the total electricity load of the day. This shows that in terms of household consumers and public services, the replacement PVP must have the capacity during daylight hours to generate more than twice the electricity needed during the day so that it can be stored and used at night, and this just for single-day, night consumption by the energy-storing unit. In its turn, the storage unit itself, with regards to non-industrial sites (meaning households and public services), must have an energy capacity of at least 70% of their maximum daily consumption for January - fig. 4, which consumption in turn is during one day of the week. It is obvious that in bad weather conditions, this capacity will not be sufficient (if you rely only on PVP for generation), while in the spring-summer-autumn period, a significant part of it will be unusable. The situation with industrial load is slightly better in terms of the need to store electricity, as predominantly industry operates during the day, but nevertheless, if we look at fig. 3 it can be seen that we will also have unusability of installed PVP in the summer months.

If the share of generating capacity for non-industrial consumers, as well as the share of energy storage units for them, is decentralized at these consumers, then the transmission capacity of existing facilities will be sufficient to "bring" the electricity generated in the summer months from centrally located PVP.

It is obvious that in order to determine the level of the required PVP, it is necessary to look for a complex solution, with a pre-selected energy storage system or systems (one-day [6], several-day [7] or long-term [8][9]), with a narrow capacity, or in consistency within the entire electricity system, with electricity producers supplying it in the dark hours of the day. Of course, the solution of the task should take into account the transmission capacities of the existing technical facilities and power lines in order to minimize the costs related to the construction of additional or new ones.

CONCLUSION

From the above it can be concluded that in order to determine what photovoltaic capacities should be built to replace coal ones, the following limitation and regulatory conditions should be take into account:

- network transmission capacity;
- seasonal, monthly and 24-hour distribution of electricity consumption, and its maxima, estimated on the basis of statistical data from previous periods, and on the basis of forecast models;
- distribution between centralized and decentralized replacement generations;
- storage of electricity - whether there will be such or not, the type of storage - one-day, several-day, long-term, its energy capacity, and energy losses associated with its storage;
- the estimated service life;
- price of stored electricity, price of unproduced electricity (due to technical limitations of electricity transmission), price of electricity produced, and minimum price of electricity sold.

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