Heuristic Methods for Sizing Solar Systems for Homes Without Specialized Measuring Devices

Nikolay Tsonev[1], Kalin Angelov[2] and Georgi Dobrev[3]

[1]*High school "Evlogi Georgiev", 14 Ferdinand Aleksandrov str, 5857 Trastenik, Bulgaria*
[2]*Sofia University "St. Kliment Ohridski" - Department for Information and In-Service Training of Teachers, 224 Tsar Boris III blvd., 1619 Sofia, Bulgaria*
[3]*Technical University of Sofia, Plovdiv branch, 25 Tsanko Dyustabanov str., 4000 Plovdiv, Bulgaria*

Abstract. This article aims, by analogy with the popular science works of Stephen Hawking, to be useful to a wider range of readers without using complex formulas or special laboratory measuring equipment. The purpose of the article is to use the ordinary household electricity meter to analyze which electrical appliances in the household can work solely on the energy generated by the solar system and thus to extract the maximum economic benefit from the installed autonomous solar power generation system.

Keywords: autonomous solar hybrid system, kilovoltampere, power, measurement, algorithm.

1. BASIC KNOWLEDGE

When an autonomous solar hybrid system for obtaining electricity is installed, we must know at least the following: 1. The structure of the construction (Fig. 1); 2. The value written on the hybrid inverter but 3.5 or 8 kVA is not automatically equalized to 3.5 or 8 kW respectively. The reduction factor of the values from kVA to kW is about 0.7 - 0.8 according to some theoretical comments, but the exact value could only be measured in laboratory conditions, which is impossible due to the wide variety of household electrical appliances in each household and the difference in the characteristics of different manufacturers. The innovation in this article is the heuristic method for sizing the reduction factor and the order in which to measure the power of each consumer to the system using the already installed standard household electricity meters to the home and a simple clock. The main requirement to implement this algorithm is that the solar system supplies one of the internal circuits of the electrical grid and that it is independent of the other circuits.

2. ALGORITHM FOR MEASUREMENTS

The preparation includes measurement of the "background" consumption in the home, including the constantly working electrical consumers: white goods, modems and black goods in stand-by mode. This consumption would probably be negligible and the results would be in the range ≈ 0 - 0.3 kW. The "test" loads used are of different types (e. g. air conditioner and cooker oven, with different cos φ). We measured their consumption according to the values of the electricity meter for 4 periods of 1 hour each. After subtracting the already measured "background" consumption in the dwelling, we calculated their average hourly consumption values. For the analysis we used a solar system (Fig. 1) with a 3 kVA hybrid inverter, two 100 Ah batteries and a 410 W solar panel.

We disconnected the central power supply and measured the operating time of the "test" loads with fully charged batteries before disconnectting the central power supply. We converted the operating time into hours and obtainned the appliance consumption in kWh, in the case of system battery power. We compared these values with their values measured at the beginning of the experiment with the power meter. We calculated the ratio of the two values and obtained the reduction factor kVA / kW (that part of the maximum power of the inverter that it actually gives to the grid, with fully charged batteries). When the load is ideal (oven) we calculated the output power in kWh. We did the same with an inductive load (air conditioner) and compared the results to measure the reduction factor and average the results. In the next chapter we evaluate the measurements made and the results obtained.

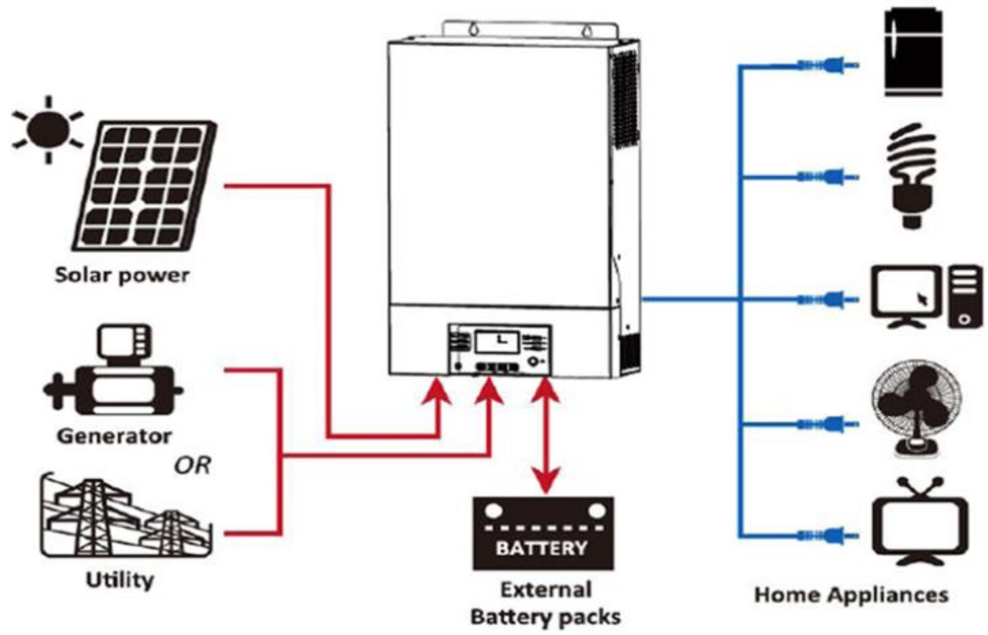

Fig. 1 Structural diagram of a hybrid solar system.

Electric appliances	Power in Watt
Toaster	1200
Oven	1600
Stoves	1250
Heater of Water	2000

Fig. 2 Power of kitchen appliances in Watts.

Electric appliances	Power in Watt
Radiator	2000
Convector	2460
Electric stove for heating	2000
Accumulative stove	3000
Air conditioner 9	950
Air conditioner 12	1750
Air conditioner 24	2600

Fig. 3 Power of kitchen appliances in Watts.

3. RESULTS OF THE MEASUREMENTS

The task set at the beginning of the study to measure the reduction coefficient for different types of loads with a traditional household electricity meter changed already at the first stage of the study, because we found that the large consumers in a household are an insignificant number. Above 1.5 kW we only measured the oven of the oven and water heater, heating stoves and the air conditioner. This raised the question of what is the optimal power of a solar system so that we fully utilize the energy generated. And the system should meet two main requirements - 1. To use all the generated energy without leaving it unused and 2. To satisfy a maximum percentage of the electricity consumption of the household. For this purpose, we used the REACH study [1] (Fig. 2 and Fig. 3). We find that the 0.8 reduction factor from kVA to kW is nearly 100 % achieved. In the interest of the reliability of the measurement, it should be specified that this is a time range with optimal conditions during the measurement (maximum solar activity in the two-week period around the autumnal equinox and absence of wind, i. e. for the solar panel (STC, Air mass) = 1.5) and fully charged batteries. At this time, the power of the oven is close to the average statistical values in households in Plovdiv, indicated in [1]. When measuring the operating time of the air conditioner - in the case of power supply from the batteries of the system, the results were interesting, but not unexpected. When operating without turning on the compressor, the air conditioner worked for 1 hour and 30 minutes without visibly affecting the capacity of the batteries, and the charging current from the panel compensated the consumption. However, when the compressor was turned on, after 15 minutes the battery charge dropped below the minimum permissible charge of 23 V to 22.7 V, which meant that the charging current of the panels no longer compensated for the consumption and discharge of the batteries. The results were expected because of the peak current values in devices with non-ideal load (cos φ < 1). Thus, the initially set task of measuring the reduction factor of the system grew, naturally, to the task of choosing the most efficient system as a consumption-investment ratio. Having established that the reduction factor of an ideal load (cos φ = 1) is 0.8, we calculated what percentage of the total consumption are such appliances [1] (Fig. 2 and Fig. 3). From the reviewed audit, we found that 38% of consumption (Fig. 5) falls on cooking appliances, lighting and other appliances that could be considered ideal loads. From the table with the average values of the specified technique, we found that their average total consumption per hour is no more than 3.5-4 kWh, observing the only condition that we do not include more than 2 large loads at the same time. This consumption could be provided by a hybrid solar system with a 5 kVA inverter at the standard reduction factor of 0.8 for this class of inverters. This makes consumption from it up to 4 kWh. More powerful systems would generate additional energy that we would not be able to use in full all the time, and the cost would be many times greater than the replacement of electrical appliances with a lower energy class.

Date	Time	Period	Consumption, kWh
07.10.2023	14:20	1 h	1.80
08.10.2023	14:15	1 h	1.67
13.10.2023	14:00	1 h	1.90
16.10.2023	14:30	1 h	1.92
	Average:	1 h	1,82

Fig. 4 Power consumption of a aven oven in kilowatt-perhours and average value.

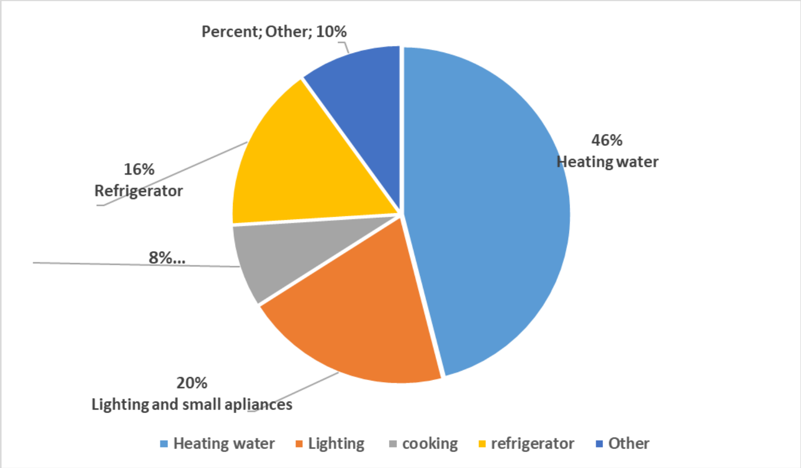

Fig. 5 Power consumption of a aven oven in kilowatt-perhours and average value.

4. EXPLANATION OF THE FACTOR COS Φ

The significance of the cos φ factor, indicating the phase difference between the electric current and voltage across various types of loads, is illustrated in graphs (Fig. 6 and Fig. 7).

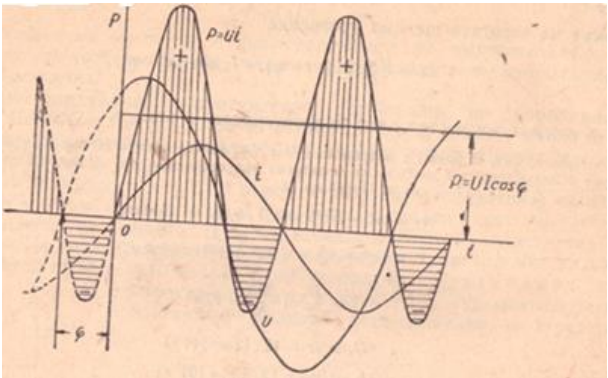

Fig. 6 Power graph with inductive load.

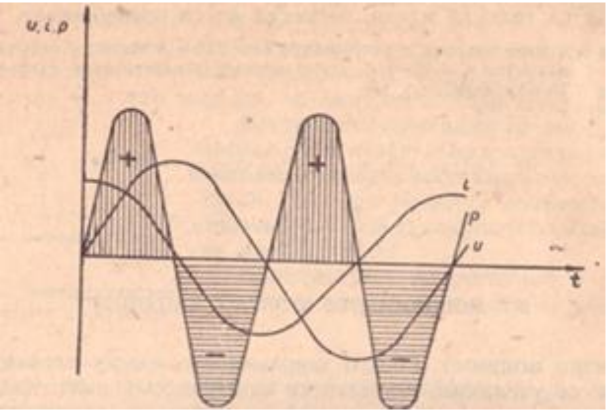

Fig. 7 Power graph with capacitive load.

5. CONCLUSION

Based on the preceding information, we conclude that the accurate sizing of hybrid solar systems is influenced not solely by specific household appliances, but also by the alteration of electricity consumption habits within households. This represents the primary innovative aspect of our analysis.

REFERENCES

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