Autonomous PV Heating System with Foil Heaters

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Abstract – This paper analyzes the possibility of create an autonomous PV heating system from foil elements with wide surface. It is proposed that the implementation is with a direct connection between the source and the load. The paper includes analysis of the technical characteristics of the installation, designing foil heater according to the source parameters and experimental study. The last option is realized by selected characteristics of the heaters.

The proposed system photovoltaic source- foil heater does not use standard inverters, which enables the construction of low-cost solutions.

***Keywords* – Foil heaters, PV systems, Heating system**

I. Introduction

The proposed photovoltaic folic-heating system aims to realize the following advantages:

• *It is possible that the system be sized for direct connection of photovoltaic strings with foil heaters. This is an opportunity to not use an inverter, which is usually expensive. Possibility of obtaining low-cost solutions is essential for autonomous household photovoltaic systems in roof structures, small drying ovens, etc.*

• *The folic heaters are low heating elements that can be designed for any supply voltage range. This allows the implementation of various schemes with series and parallel connection of modules that meet specific performance requirements. The dimension is done in certain parameters of the nominal power system.*

• *The system is maximum simple and reliable. The additional items tof the installation can be a voltage stabilizer, UPS system etc.*

• *The foil elements with wide surface allow obtaining uniform distribution of the temperature field in the room. This is essential for certain types of technological equipment such as dryers, etc. The above mentioned condition can not be realized through the widespread use of spiral tubular or other heaters and domestic heating appliances standard [1], [2], [3].*

II. Analyses

The principal electric scheme of the photovoltaic system with foil heaters is shown in Fig.1.

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Design [1], [2], [3] of the foil heater is preceded by preliminary heat technical calculations, related with the determination of the geometric dimensions of the heat transfer surface of the heating element. As a result geometric dimensions of the equivalent smooth surface, on which the heater is placed, are defined. When designing the foil heater, the following restrictive conditions are used:

• Technological options for its implementation on a certain area, given operating temperature and power supply voltage.

• Electrical safety and electrical insulation strength.

The implementation of the proposed system requires the design of a foil heater according to the parameters of the photovoltaic system. It is necessary the classical design methodology [1], [2], [3] to be harmonized with the electrical parameters used in PV source. Overall mode of the foil heater with wide surface is shown in Figure 2.

When designing foil heaters with wide surface, according to [1], [2] [3] are set:

• P_1 and P_2 – the electric power of both heating elements must be complied with the required heating of the room;

• τ_n - temperature of heat transfer surface temperature of the heater (work temperature). It is defined at sizes c and f (Fig. 2), when working with power $P = P_1 + P_2$;

• U - power supply voltage, which is determined by the method of connecting the photovoltaic elements;

• a - thick of metallic layer of material from which the heater is made.

The design involves specifying the width of the metal bands b_1 and b_2 and the number of connected in series strips n.

According to indications from Figure 2 the following expressions for real electrical resistances of two heating elements are:

$$R_1 = \frac{n.\rho_t.l_s}{a.b_1}[\Omega]; \quad R_1 = \frac{n.\rho_t.l_s}{a.b_2}[\Omega]; \qquad (1)$$

n – numbers of metal strips;

l_s – average length of a strip - $l_s = c + \Delta$;

ρ_1 – resistivity of the metallic layer at operating temperature τ_n.

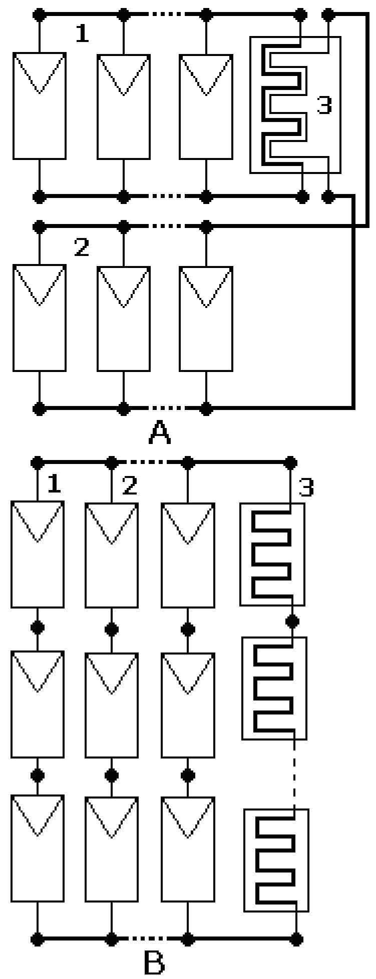

Fig. 1 The system photovoltaic strings (1.2) with a foil heater (3). A - parallel connection of the modules when the foil heater is with two parallel stripes; C –connection in series

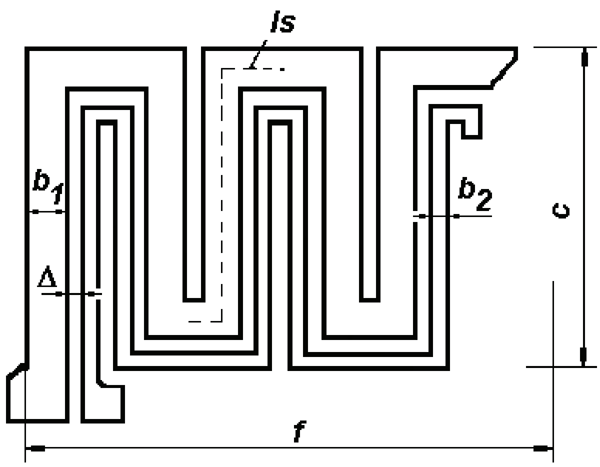

Fig. 2. Foil heater

If it should be affixed:

$$K = \frac{P_1}{P_2} \text{ it follows: } K = \frac{b_1}{b_2}; \quad K = \frac{R_2}{R_1}.$$

Provided that two heating elements operate in parallel:

$$R_e = \frac{R_2}{1+K}$$

From the expression of power $P_1 + P_2 = \frac{U^2}{R_e}$.

In such a case occurs $P_2 = \frac{U^2.a.b_2}{n.\rho_t.(c+\Delta)}$.

Full surface of the heater expressed by the geometric dimensions *c*, *f*, *n*, *b2* and *k* is:

$$S_{ne} = c.f = n.[2.\Delta + b_2.(1+K)].c \quad (2)$$

The number *n* of two strips heater element is:

$$n = \frac{f}{2.\Delta + b_2.(1+K)} \quad (3)$$

The error that is allowed by formula (3) consists of non-recording of an area between two adjacent strips, but when a large number of bands *n*, it is insignificant.

Quadratic equation in terms of a species:

$$(1+K).b_2^2 + 2.\Delta.b_2 - \frac{P_2.f.\rho_t.(c+\Delta)}{U^2.a} = 0 \quad (4)$$

If: $A = \frac{P_2.f.\rho_t.(c+\Delta)}{U^2.a}$

The equation for determining the width of the stripe b_2 of the heating element with power P_2 is:

$$b_2 = \frac{1}{K+1}\left(\sqrt{\Delta^2 + A(K+1)} - \Delta\right) \quad (5)$$

For complete dimensioning of two heating elements it is necessary to allocate and b_1 and *n*.

Coefficient of filling K_z of the heating element is determined as a ratio between the surface, occupied by the metal stripe on the heating element, and the total area of the heater, determined by the sizes *f* and *c*:

$$K_z = \frac{(c+\Delta).b_2.(1+K)}{c.[2.\Delta + b_2(1+K)]} \quad (6)$$

There are three cases [1],[2],[3]:

Both heating elements are with the same power: $P_1=P_2=P$; K=1

$$b_1 = b_2 = b = \frac{1}{2}\left(\sqrt{\Delta^2 + 2A} - \Delta\right) \quad (7)$$

The number of stripes ***n*** is:

$$n = \frac{f}{2.(b+\Delta)}; \quad K_z = \frac{b.(c+\Delta)}{c.(b+\Delta)}$$

In this case they can be connected in parallel with the power of a common string or a separate power Fig.2. The second method is applicable for fixed roof where both strings are with different orientation.

Heater consists of a heating element with power P:

$$b = -\frac{\Delta}{2} + \sqrt{\frac{\Delta^2}{4} + \frac{P.f.\rho_t.(c+\Delta)}{U^2.a}} = = \frac{1}{2}\left(\sqrt{\Delta^2 + 4A} - \Delta\right) \quad (8)$$

$$n = \frac{f}{(b+\Delta)}; K_z = \frac{b.(c+\Delta)}{c.(b+\Delta)}$$

Instead of sizes *c* and *f* their relationship is set:

$$m = \frac{f}{c}; \quad S = c.f \quad (9)$$

The width of the stripe:

$$b = -\frac{\Delta}{2} + \sqrt{\frac{\Delta^2}{4} + \frac{P.\rho_t.S.(1+\Delta.(m/s)^{-2})}{U^2.a}} \quad (10)$$

Number of stripes:

$$n = \frac{\sqrt{m.s}}{b+\Delta} \quad (11)$$

Proposed equations (1-11) show the relation between the electrical parameters of the system (photovoltaic string - foil heater) and the geometric characteristics of the heating part. Thus allows sizing of the installation area according to required surface of the heater for the specific case under consideration.

It should be noted that the structure is possible and with wind and / or hybrid systems, but proposed realization is with photovoltaic modules. The main advantage is the possibility of obtaining the different electrical parameters of the supply system and the opportunity for sizing heaters with different characteristics. The design of PV system is carried out by established methods [4], [5].

Experimental study was done over photovoltaic system with 36 modules, 2,16 kW, 1000W/m^2 and 25^{0}C (STC). The location of the systems is 43.12, 47.55 - Varna. The proposed figures show:

- Fig.3. - Current and voltage of the system for five days - October;
- Figure 4 - current and voltage of the system for five days - August. The heating system is tested and during the summer months for comparison purposes.
- Fig.5 - output voltages (October) in organizing the different strings, which depends on foil heater sizing:
- Graph 1 - 2 (in module string) / 18 (string);
- Chart 2 - 3 / 12;
- Figure 4 - 6 / 6;
- Chart 3 - 4 / 9;
- Fig. 6 - output current in the organization of different strings. The name of the graph is as Fig. 5.
- Fig. 7 - Power system working day of October.

III. CONCLUSION

Performed theoretical analysis and experiments confirmed the above mentioned advantages of using folic heating technology to build an autonomous heating system powered by photovoltaic modules.

The proposed study shows that the parameters of photovoltaic systems provide the opportunity for a heating system with the foil heaters. The design is performed in a wide range of electrical parameters, which depend on the method of connection and building strings. Determine the number of heating elements with appropriate size and power is available as required by the heating facility. Thus heating system that meets the specific temperature requirements for distribution is realized. Opportunity for direct connection of heaters and photovoltaic elements creates conditions for increasing the efficiency of utilization of solar energy.

REFERENCES

[1] Panayotov Design of electric heaters for low-folic-type heaters. Ph.D. dissertation. Varna, 1986.

[2] Panayotov S. I. Kontrov. Summary methodology for the calculation of surface electric heater - foil type with deeply wavy shape. Scientific Session TU- Gabrovo, 1981.

[3] Panayotov S. I. Kontrov. Optimization of some design parameters of heat-convections foils heaters. TEHMA 88, MIC-Varna, 1988.

[4] Markvart T., L. CastanerPractical Handbook of Photovoltaics: Fundamentals and Applications. Elsevier Science Inc. 2003.

[5] Messenger R. J. Venture. Photovoltaic System Engineering. CRC Press LLC 2004.

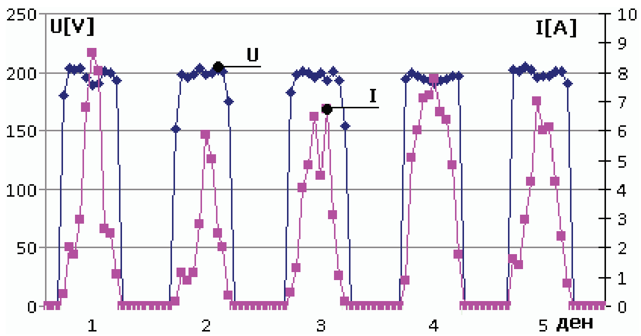

Fig. 3. Voltage and current for five working days of October

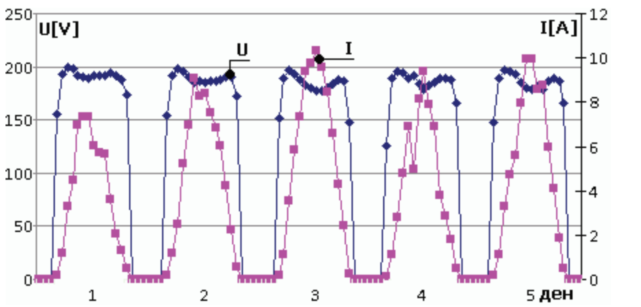

Fig. 4. Voltage and current for five working days of August

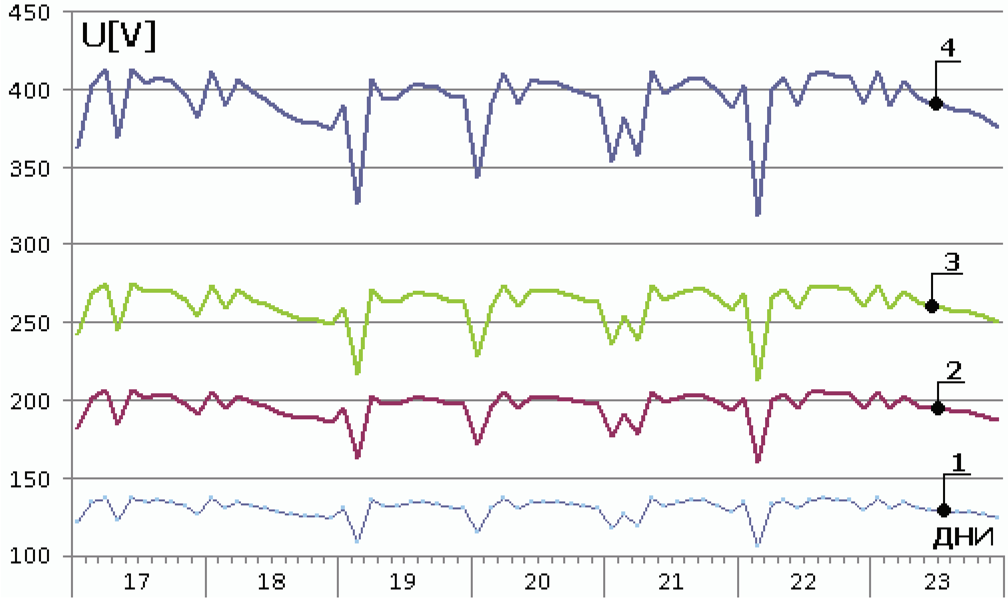

Fig. 5. Voltage photovoltaic system in different arrangements of strings:
1-2 (in module string) / 18 (string) 2 - 3 / 12, 3 - 4 / 9, 4 - 6 / 6

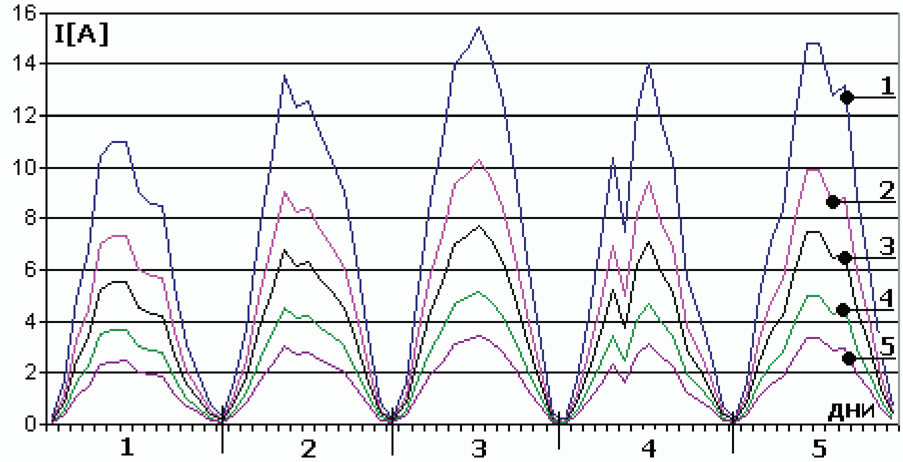

Fig. 6. Photovoltaic power system with different arrangements of strings:
1-2 (in module string) / 18 (string) 2 - 3 / 12, 3 - 4 / 9, 4 - 6 / 6

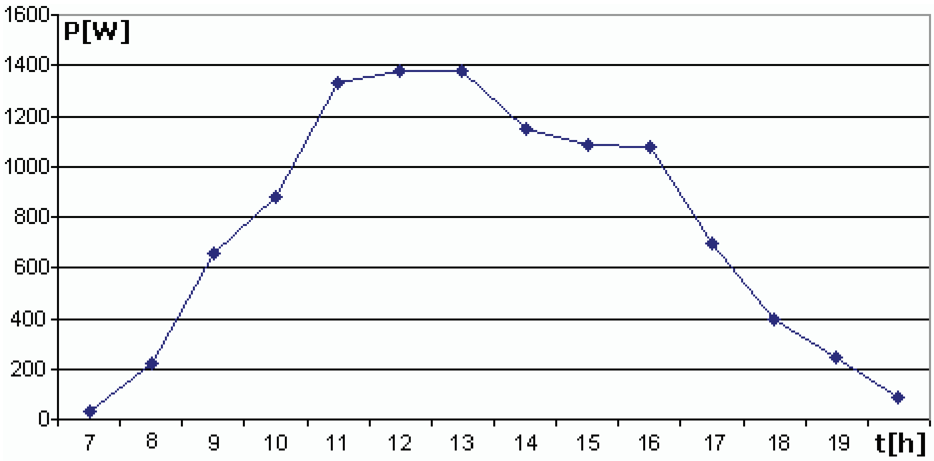

Fig. 7. Photovoltaic power systems within one working day of October