ACTA TECHNICA CORVINIENSIS
– Bulletin of Engineering
Tome X [2017]
Fascicule 4 [October – December]
ISSN: 2067 – 3809

[1.]István BODNÁR, [2.]Ádám SKRIBANEK

OPERATING EXAMINATION OF AN OFF-GRID SOLAR SYSTEM IN CASE OF INDUCTIVE NATURED LOADS

[1.-2.]Institute of Electrical and Electronic Engineering, Faculty of Mechanical Engineering and Informatics, University of Miskolc, Miskolc, HUNGARY

Abstract: Two ways of solar energy utilization is distinguished. These are the so called passive and the active forms. Passive solar energy utilization means energetically more favourable orientation of buildings. The conscious building orientation is discernible since the ancient times, to take advantage of the solar radiation. In this publication after a short description of solar energy utilization, the temperature dependence of solar panels is described. A compiled off-grid solar system is also presented and the system efficiencies, maximum loads, current and voltage waveforms together with other measurement results in case of different load levels are described. The final system's operability and the switch-over are shown too.
Keywords: Solar energy, temperature dependence, off-grid, UPS

INTRODUCTION

Energy is one of the centre elements of our world. The renewable energy sources, mainly the Sun increasingly came to the view nowadays, so the subject of examining solar power production is very actual. The Sun is not only the base of ground life, but the central planet of our Solar System too. Fusion processes are taking place inside of the Sun, where hydrogen atoms combine into helium atoms. The weight loss (4 million ton/sec) that comes into being during the reaction transforms into energy. About180 million kWh energy is released during the formation of 1 kg helium. The energy of solar radiation is 1.37 kW/m^2 at the edge of our atmosphere, this is called solar constant. The energy of this solar radiation at the earth's surface is much lower, maximum 1.000 W/m^{2}can be measured at a sunny summer day. Third of this number is direct radiation and the rest is called scattered light [3, 7].

If the energy that reaches the top of the atmosphere counts as 100%, than the direct radiation on the surface is 33% while the scattered is only 18% of that energy. The sum of these two numbers means the global radiation. 10% of the global radiation is reflected by the surface. The composition of the radiation defines its usability [3, 7].

Two ways of solar energy utilization is distinguished. These are the so called passive and the active forms. Passive solar energy utilization means energetically more favourable orientation of buildings. The conscious building orientation is discernible since the ancient times, to take advantage of the solar radiation.

Active solar energy utilization happens with the help of solar panels. With these solar panels it is possible to produce electricity or directly heat from solar radiation. Heat production means heating water for different reasons. Energy production nowadays can happen even at the roof of a family house in an environmental friendly way.

As the internal resistance of solar panels is influenced by its temperature and the intensity as well, it is needed to set the same resistance as a load to produce the maximum electrical power [1, 2, 7].

TEMPERATURE DEPENDENCE OF SOLAR PANEL'S VOLTAGE AND CURRENT

U_{oc} open circuit voltage and I_{sc} short circuit current can be measured on solar panels. If any load is connected to the solar panels, the measureable I current and U voltage will always be lower than in case of no load. The I current is the difference between the dark current (I_{dark}) and the photo current (I_{photo}). The dark current exponentially depends on the temperature and linearly depends on the

I_s saturation current because of the semiconductor character of solar panels. This is described by the equation (1) [1, 4, 5]:

$$I = I_{dark} - I_{photo} = I_s\left[\exp\left(\frac{eU}{kT}\right) - 1\right] - I_{photo} \quad (1)$$

The short-circuit current (2) and the open circuit voltage (3) can be expressed by the substitution ofU=0 and I=0.Open circuit voltage logarithmically depends on current values and linearly depends onU_T temperature dependent thermic voltage. According to these [1]:

$$I_{sc} = I_{photo}\,, \quad (2)$$

$$U_{oc} = \frac{kT}{e}\ln\left(\frac{I_{photo}}{I_s} + 1\right) = U_T\ln\left(\frac{I_{photo}}{I_s} + 1\right) \quad (3)$$

The U-I characteristics can be seen on Figure 1 in case of different intensities of illumination.

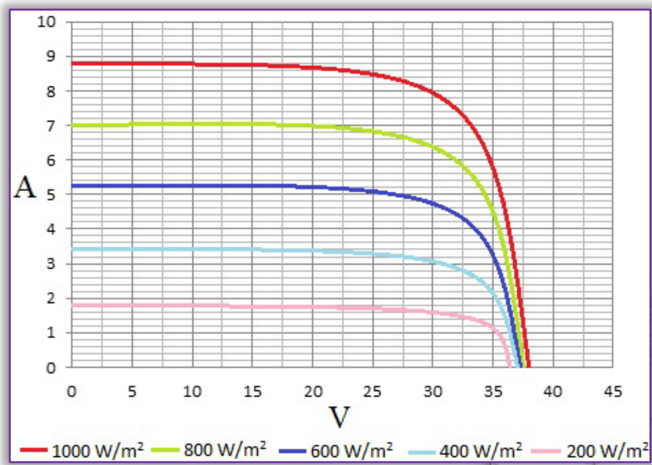

Figure 1- Voltage-amperage characteristics of solar panels in case of different intensities

It can be seen, that the short circuit current is directly proportional to the intensity of illumination, as the value of the photocurrent increases by light intensity increase and equation (2) says that the photocurrent equals to the short circuit current. It can also be seen in equation (3), that the idle voltage logarithmically depends on the intensity of illumination.

TEMPERATURE DEPENDENCE OF ELECTRICAL POWER AND EFFICIENCY

Effective electrical power (P) of the solar panel can be determined by the multiplication of the I amperage and U voltage measured on the R resistance [1, 4, 5]:

$$P = IU = I_{sc}U - I_sU\exp\left(\frac{U}{U_T} - 1\right) \quad (4)$$

To produce the maximum electrical power, it is needed to suit the electrical load. To find the extreme values of equation (3), it is needed to partially derive the function as the solution of the $\frac{\partial P}{\partial U} = 0$ equation is needed. The amperage of the operating point (5) and its voltage (6) can be determined this way [1, 4, 5]:

$$I_m = -\frac{U_m}{U_T}I_s\exp\frac{U_m}{U_T} \approx -I_{sc}\left(1 - \frac{U_T}{U_m}\right) \quad (5)$$

$$U_m = U_0 - U_T\ln\left(1 + \frac{U_m}{U_T}\right) \quad (6)$$

The optimal value of load can be determined from equation (5) according to Ohm's law [1, 4, 5]:

$$R_m = -\frac{U_m}{I_m} = \frac{U_T}{I_s\exp\left(\frac{U_m}{U_T}\right)} = \frac{U_T}{I_m + I_s + I_{sc}} \quad (7)$$

The value of load resistance ideally equals to the solar panel's internal resistance. The so called fill factor (φ) shows how the multiplication of operating voltage (U_m) and amperage (I_m) relate to the multiplication of open circuit voltage and short circuit amperage [4, 5]:

$$\varphi = \frac{U_m I_m}{U_{oc} I_{sc}} \quad (8)$$

The value of the fill factor depends on the illumination and the chosen operating point [4, 5,]. The value of the φ in case of solar panels used in practice, moves between 0.75 and 0.85. It can be seen that the fill factor shows how the square of the maximum operating power (grey square) relates to the square of the multiplication of I_{sc} and U_{oc} on Figure 2.

The maximum efficiency of the solar panel (η_{max})can be counted by dividing the maximum operating power of the solar panel and the light power (P_{light})on the effective surface [4, 5]:

$$\eta_{max} = \frac{I_m U_m}{P_{light}} = \frac{\varphi I_{sc} U_{oc}}{P_{light}} \quad (9)$$

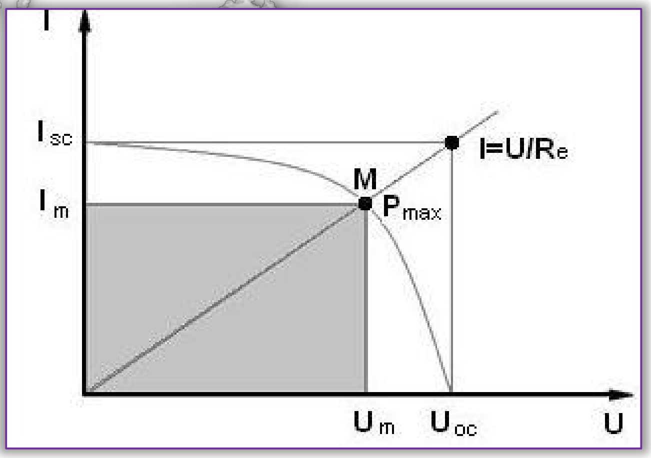

Figure 2-The operating point (OP) of maximum power on the U-I characteristic of solar panels

THE MEASURING SYSTEM

Measurements were made with two CFSR-SP250W polycrystalline solar panels operating in parallel. The maximum power of this kind of solar panel is 250 W, but the value of the electrical power is affected by the temperature dependence of the PV, the intensity of illumination, the resistance of the electrical load, the age of the solar panel and their orientation, so the power of solar panels was measured too during the measurement, using MPPT (Maximum Power Point Tracking) charge controller, which follows and sets the right load resistance to produce maximum electrical power [6]. The two solar panels were placed on the roofing of the workshop hall at the University of Miskolc, as it can be seen on Figure 3.

Figure 3 -Solar panels used for the measurement

THE COMPILED SYSTEM

The solar cables, the battery and the inverter are directly connected to the charge controller. The maximum current of the charge controller is 30A and it was charging a 90 Ah, 12 V car battery with a maximum of 720 A start-up current. DC was transformed to AC by a maximum of 1 kW effective powered, 12 V inverter. The switching between the energy sources was provided by a US-12N automatic switching station. A boiler pump with 3 power levels and an electric drill was applied as electrical loads.

With the help of the right instruments, which were CAT analysers, it was possible to measure the voltage of the solar panels and the battery together with their current, on both DC and AC sides. The electrical power of the battery and the solar panels together with the efficiency of the system in case of different loads were measured too. The compiled system can be seen on Figure 4.

The compiled system proved to be functional. Blackouts were simulated by switching off the household power manually. As the effect of the simulated blackout, the switching station automatically switched-over to the alternative energy source, and the load device was operating flawlessly. When the household power was switched back on, the switching station switched back to that in a short time.

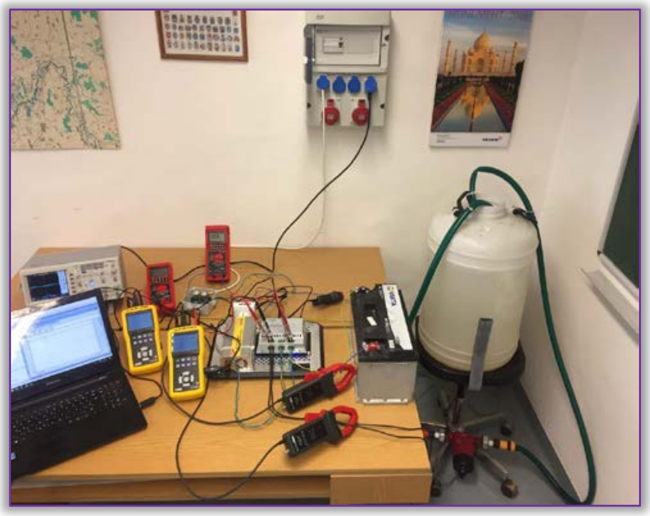

Figure 4 -The compiled measuring system

MEASUREMENT RESULTS

Efficiency measurement

During the efficiency measurement inductive natured loads were applied, like a boiler pump and an electric drill. The battery was disconnected from the system while the boiler pump operated, but in case of the drill it was connected too, because of the high amperage while starting-up. Table 1 contains the measurement results.

Table 1 – Efficiency measurement results

	Boiler Pump			Drill
	I. level	II. level	III. level	
P_{pv}	-17.1 W	-34.4 W	-57.5 W	-235 W
$P_{battery}$	0 W	0 W	0 W	-135 W
P_{load}	8 W	23 W	44 W	308 W
Efficiency	46.78%	66.86%	76.50%	83.24%

In case of connecting a greater load to the system than the maximum power of solar panels, the extra energy is provided by the battery. The last column of Table 1 contains the measurement results of this case.

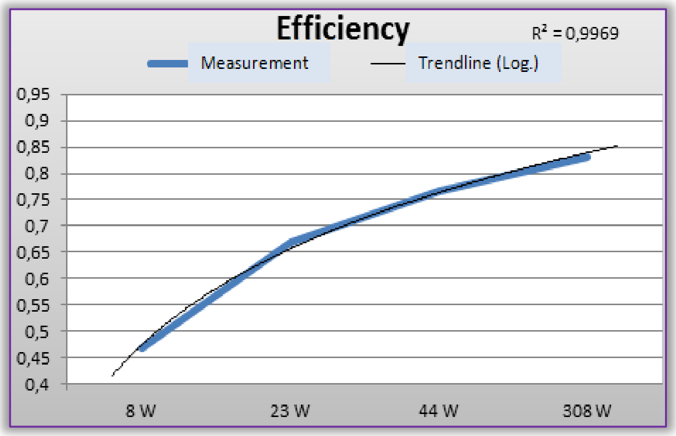

Figure 5 – System efficiencies in case of different loads

Figure 5 shows the system efficiencies in case of different loads. The efficiency of the system is almost the same as the efficiency of the inverter. It can be seen that the increasing value of electrical load increases the efficiency of the inverter too, until the maximum power of the inverter is reached.

Current and voltage waveforms

The battery was connected to the system during the measurement of voltage and amperage of the boiler pump, which operated on maximum power.

Figure 6 contains the measurement results, where the darker line is the current while the lighter one is the voltage waveform. It is noticeable that the voltage of solar panels decreases exactly when its current increases, as the multiplication of these values give the power of solar panels.

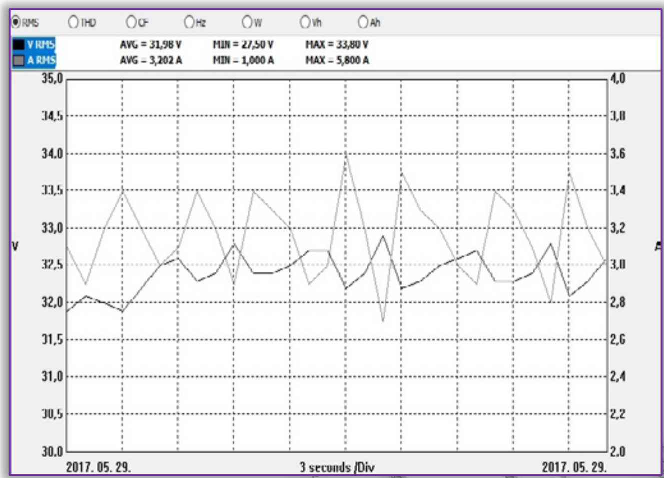

Figure 6 – Current and voltage waveforms

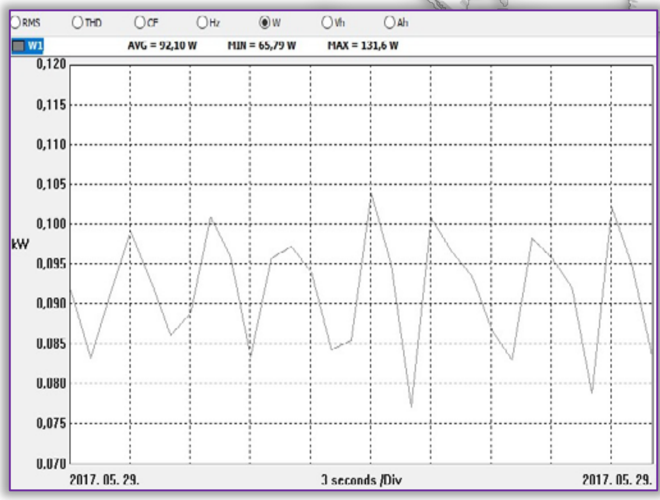

Figure 7 – The power of solar panels

Figure 7 shows that the average power of the solar panels was 92.1 W. The system used up 44 W to operate the boiler pump and 12 W to charge the battery. The rest power was power loss in the system.

The primary energy sources of the charge controller were the solar panels. At the time of the measurement, the maximum power of solar panels was 235 W, the rest energy that needed to operate was provided by the battery. The waveforms of solar panels were smoothed, as they provided their maximum power during the examination. Figure 8 shows these waveforms.

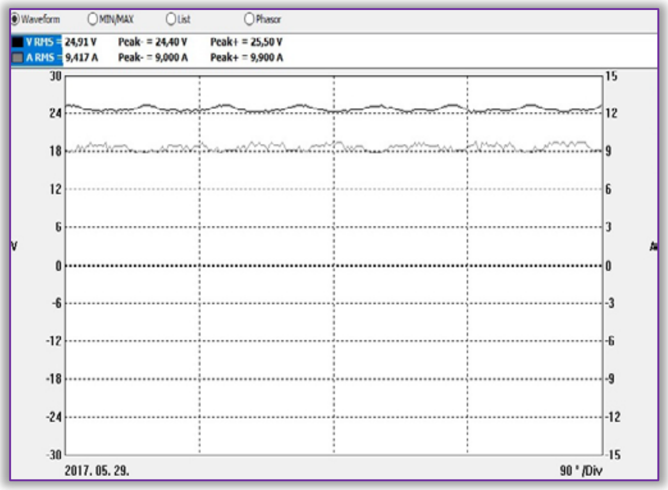

Figure 8 – Voltage and current of solar panels in case of operating a drill

Start-up current

Inductive natured electrical loads need high current while starting-up. Solar panels are not able to provide this high current, so it is provided by the battery during starting-up. Later on, during the operation of the boiler pump the solar panels provide the required electrical power. The waveform of this high current can be seen on Figure 9.

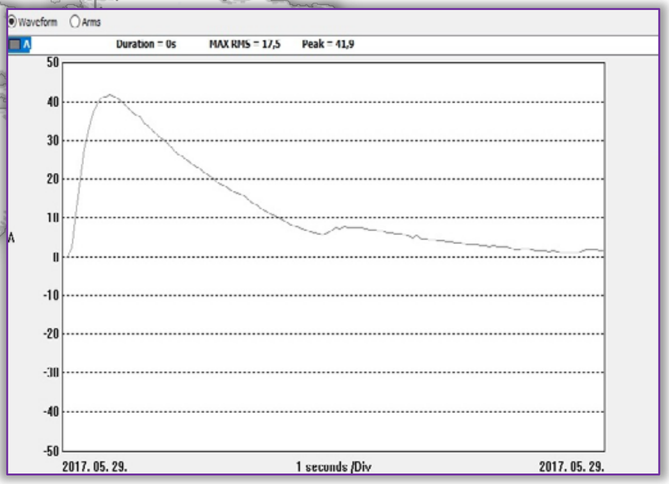

Figure 9 – Start-up current in case of operating a boiler pump

Figure 9 also shows that the maximum of this current is 42 A in case of the boiler pump. Operating the drill leads to higher start-up current with a similar waveform. In case of the 308 W electrical drill, this maximum amperage was 113 A, so it can be said that higher power requires higher start-up current too.

Switch-over

As an automatic switching station was also connected to the system, it was possible to create an uninterruptable power supply system. For this, it was needed to choose the household power as the primary and the inverter as the secondary energy source of the system. In case of a blackout, the operating of the device is assured by the alternative energy source. The effective voltage of household power was 229 V, while in case of the inverter it was 237.5 V. Because of this effective voltage difference, the two energy sources are differentiable on Figure 10, where the switch-over can be seen. The blackout was simulated by turning off the circuit breaker of household power manually. The switch-over was so quick that the boiler pump did not turn off during it.

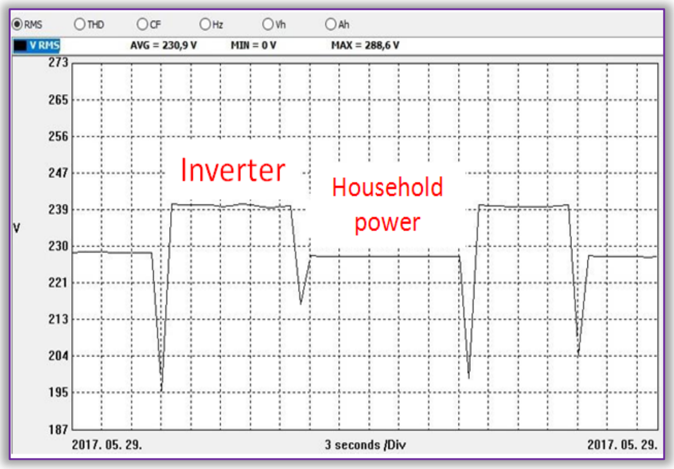

Figure 10 – Switching-over the energy sources

SUMMARY

The designed and compiled system proved to be functional. The MPPT mode is necessary for producing the maximum power because of the intensity and temperature dependence of solar panels, which can be counted by the mentioned equations above. It is important to find and set the internal resistance of solar panels as load resistance.

The blackout of the household power was simulated by switching off the circuit breaker of household power manually. The switching station automatically recognized it and switched-over to the alternative energy source until the blackout was over. This proved that the compiled system works as a safe uninterruptable power supply system (UPS).

As it can be seen, the battery is an important part of the system, because in case of inductive natured loads, the start-up current is provided by it. Also important to mention that the battery is the only part of the system that can store energy and provide it even at night, when there is no sunshine.

Nowadays it is very important to take care of our planet and solve the energy problem of the population. Solar energy together with other renewable energy utilization may be the solution of this problem but it is still needed to develop the current technology of solar energy utilization to reach higher efficiencies.

References

[1] SZÁSZ, CS.: Optimal control of Photovoltaic Modules Energy Efficiency. Journal of Computer Science and Control Systems. Vol. 10. Nr. 1. pp. 29-34. 2017.
[2] HERSCH, P.: Basic photovoltaic principles and methods. United States Department for Energy. USA, 1982.
[3] DR. MIZSEI, J.: Napelemek laboratórium. Segédlet. Budapest, 2003.
[4] KING, L.D., KRATOHVIL, A.J., BOYSON, E.W.: Temperature Coefficients for PV Modules and Arrays: Measurement Methods, Difficulties, and Results, 26th IEEE Photovoltaic Specialists Conference, Anaheim, California, 1997.
[5] DUBEY, S., SARVAIYA, J.N., SESHADRI, B.: Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World-A Review. Energy Procedia 33. pp. 311–321. 2013.
[6] MALIK, A.Q., DAMIT, S.J.B.H., Outdoor testing of single crystal silicon solarcells. Renewable Energy 28. pp. 1433–1445. 2003.
[7] KOVÁCS, CS.:Napelemek működése és alkalmazásai, Budapest, 2008.

ISSN:2067-3809