Design and Simulation of the Solar Street Lighting Photovoltaic System with LED Energy Lamp

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Abstract

This article describes the modeling and simulation of photovoltaic street lighting systems and a design concept of the power of LED lighting units proposed to use in areas with moderate solar potential. In finally is determined the contribution value of carbon dioxide emissions by replacing the traditional street lamps with LED lighting, solar lamps.

Keywords: modelling, simulation , photovoltaic street lamp

1. Introduction

Energy efficiency low" 199/2000 indicated the national policy direction of efficient use of energy, according to the Energy Charter and Protocol on energy efficiency the low proposed environmental obligations for the energy producers and instituting incentives for the consumers. In energy low 13/2007 has two capitols for promoting the use of renewable energy sources, electricity production with these alternative sources and uses high efficiency cogeneration methods.

This paper describes a case study for solar street lighting system indicated to be installed in Romanian Central Region 7. One way to respect this indication of the energy low is to renew the street lighting equipment that can be realized with helpful of solar street lighting units with LED energy efficient lamps. That is very durable, can easy install and operate and reduce pronounced the energy consumption.

The solar led lamp consumes up to 72 % less energy than other light sources, has a lifetime up to 100000 hours that means 10 years continuous use. With brightness up to 80 Lumens/Watt, LED light outperforms incandescent, halogen and neon light sources.

The principal component of the solar street lighting system is a stand alone, off grid photovoltaic energy supply system, which produced energy for DC consumers. The paper presented the principles and design method for planning the of – stand alone photovoltaic supply system.

The design method starts with analyzing the solar radiation potential in application site. That can be realized with helpful of different solar radiations maps. In Romania on a horizontal surface of 1 m^2 it is possible to capture in one year period, energy between 900 - 1450 kWh, depending on the season. For the Central region this value is 1200-1300 kWh/ m^2, year.

The paper presented the technical structure of the system, the evaluation parameters is calculated from energy balance and is used to estimate to the amount of photovoltaic generated electrical energy and actually value used by the consumer. In following is presented the evaluation parameters of the stand alone system; SOC, array load ratio and the energy yield. Those parameters make possible to compare results from different system components, operation management modes or systems at different locations. (Morgan et all) The system parameters have been evaluated with use of computer –aided design and simulation software. In finally of the paper is presented same environmentally aspects for advantages of use of solar street lighting systems. Use this street lighting system the consumer eliminate the dependency on growing cost of the electricity price.

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2. Modelling and simulation of the energy supply system for LED lamp lighting system

The stand alone solar street lights system is built from PV panel, which adsorb the solar energy during daytime. The PV cells convert the solar radiation into electrical energy which is stored in the battery bank, at the nighttimes the lamp start automatically and it consumes the electricity already stored in battery.

During the day time the battery gets recharged and the process keeps on repeating every day. (Lawrance)

The commercial system can light the streets from 4 to 12 hours depending of the size of PV panel and battery. The structural scheme of the solar street light system is presented in figure 1. (Morgan)

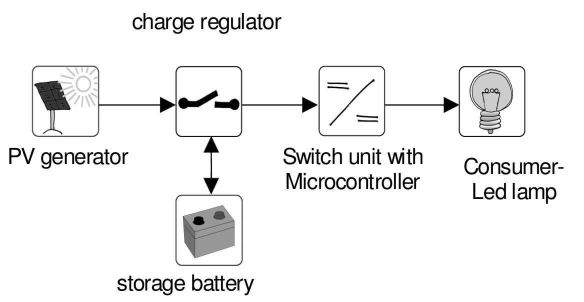

Figure 1. Principal structure of the photovoltaic street light system, (Source: Fraunhofer ISE, Freiburg, Germany).

2.1. Solar energy potential

The process of the modelling of the energy supply system starts with the study of the solar energy potential of the application site.

Romania has moderate solar energy thought to the whole of country. The best solar recourses are located in a southern region of the country.

It is know that for the Central Region 7 have lower values of the solar energy potential, like in South parts of Romania.

If a PV application is installed in this region is indicated to the designer to realise a preliminary measurement of this potential in the location site.

That can be realised with helpful of the solar radiation sensors installed at the PV plant location and connecting to one data logger unit.

The structure of the experimental solar radiation potential measurement can be seeing in figure 2.

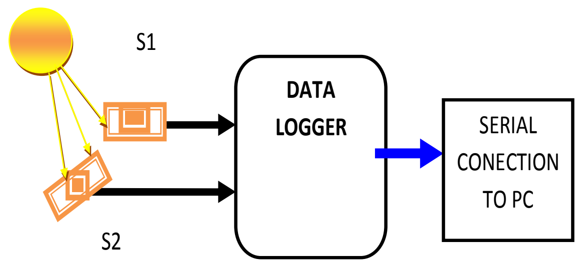

Figure 2. Structural scheme of the Solar radiation measurement unit

The system used two sensors, S_1, S_2 and that measured the global solar energy values at horizontal plane and in inclination plan of the PV panels. The measured value of the sensors by 1 s sampling time is stored in a Data logger unit and will be evaluated by the designer, transformed the measured value in mV in Irradiance [W/m^2].(Lawrance et all) The logger stored this measured data in MS Office –Excel compatibles form. The solar refinance varies throughout the day from 0 W/m^2 to 1000W/m^2, these values is strongly depended on location and local weather. The used sensor has the following technical parameters:

– Spectral range: 400-1100 nm,
– Sensitivity, 60-100 µV/W/m²,
– Response time < 500 ns,
– Operating temperature – 30…+70°C

2.2. The load profile

The first step in a modelling of the solar street lighting system is to determine the lighting load, which can be established with the determination of the necessary illumination level. That can be measured in W/m^2, or in foot- candles. Determination of the wattage of light needed to accomplish a specific lighting task that depended on the required illumination level and the area to be lighted. In the present case study the simulation results indicated the energy balance of one LED lamp supplying with a PV stand alone system. The daily energy consumed by this application is 0.3 kWh/day. In this case the lamp is working from sunset to sunrise, that can be operate 13 h during the month of December if the lights come 15 min after sunset and shut off 15 min before sunrise. During the month of June, the fixture will only need to operate for 8-9 h. The sun rise and the sunset time we can find in different meteorological WebPages for different regions. If the lamp power is 30W the daily energy loads in winter period is 390 Wh/day and in summer period is 294 Wh/day. The case study presents the energy balance of the LED lighting system with a general daily load 300 Wh/ day.

2.3. The PV system availability

The critical loads are defined as loads for which loads for which power is required at least 99% of the time. Noncritical loads require at least 95% of the time. In case of stand alone system is necessary to evaluate the storage days in case of noncritical and critical systems.

That can be realised with helpful of the method presented by the Sandia National Laboratory. That value is function of the peak sun hors of the application sites. The mathematical equation used in case of critical PV application is: (Messener et all)

$$D_{crit} = 0.2976 \cdot T_{\min}^2 - 4.7262 \cdot T_{\min} + 24 \quad (1.1)$$

And in case for non critical application the used function is:

$$D_{non} = 0.1071 \cdot T_{\min}^2 - 1.869 \cdot T_{\min} + 9.4286 \quad (1..2)$$

For a stand alone systems the necessary days of battery backup storage unit can be evaluate with this equations knowing the available peak sun hours. In application site of PV Street lighting this value is 2 hours and using the presented equation can be calculated days of the battery bank autonomy.

2.4. Determination of the array

The theoretically array size can be determined by first calculating the energy that must by supplied to the battery bank by the PV array.

For a winter period the connected load on the battery is 390Wh/ day, and because losses of 10% can be expected for battery charging/discharging and an additional 2% for wiring losses, a total of 390/0.9/0.98=442.17Wh/day must by supplied to the battery by the array each day.

The array is connected to the batteries through an MPPT charge controller and take into account the combination of the charge controller and wiring from array to charger have an efficiency of 96 %,the array must generate 442.17/0.96=460.6Wh/day. Allowing for 12 % losses due to evaluated the temperatures, soling, and mismatch the PV array most be sized to generated 460.6/0.88=523.4 Wh/day.

The PV array will be tilted at 35 and the average daily in application site is 1.790 kWh/m² day. From this data can be calculated the array rating in kWatts:0.5244/1.790=0.292kWp=300W_p.

This panel can be built using two 150W_p modules in series connected. For the practical solution is proposed a smaller energy supplying system.

3. PV system design and simulation results , discussion

The technical solution of this stand alone system is presented in figure 3. (Quasching)

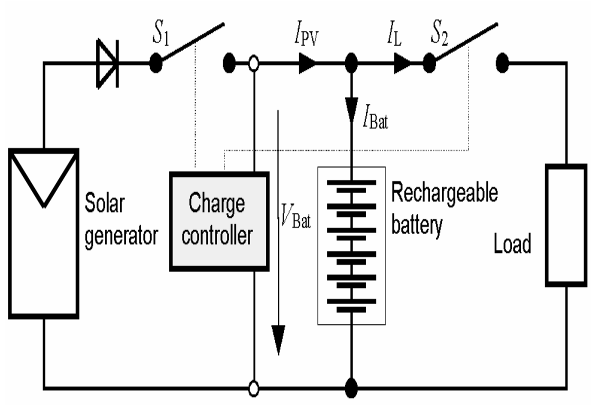

Figure 3. Technical connection scheme of the stand aloe PV light system with a Led lamp

This system can be realized with the following components:

- 2 PV module**,** Kyocera KC 85T-1 with the following technical parameters:
- Rated Power, 87.3 [W]
- Peak Power Voltage, (V_{mpp})**,** 17.4 [V]
- Peak Power Amps, 5.02 (I_{mpp}), [A]
- Open Circuit Voltage (Voc), 21.7 [V]
- Short Circuit Amps (Isc), 5.34 [A]

One charge controller, CXN10, connected to battery, S12 230 AGM type, this battery has extremely low internal resistance, that giving them a very low self discharge rate. The LED lamp is connected to the PV sources by the microcontroller unit that is programmed to respect the lighting period at application site.

The solar energy potential of the application site has been evaluate using the PV GIS model and the average daily value of the solar energy is presented in table 1.

Table 1. Solar radiation and the energy balance date of the PV stand alone system

Month	Eday (kWh/day)	Em (kWh/m)	E day load (kWh/d)	Hd (kWh/d)
Jan.	0.31	9.56	0.3	2.16
Feb.	0.44	12.4	0.3	3.17
Mar.	0.58	18.1	0.3	4.33
Apr.	0.64	19.1	0.3	4.92
May.	0.72	22.3	0.3	5.74
Jun.	0.71	21.2	0.3	5.73
Jul.	0.74	23.1	0.3	6.05
Aug.	0.75	23.2	0.3	6.04
Sep.	0.65	19.3	0.3	5.02
Oct.	0.56	17.3	0.3	4.22
Nov.	0.34	10	0.3	2.42
Dec.	0.24	7.55	0.3	1.71
Yearly average	0.557	16.9		4.3
Total for year		203		

This table show the following parameters of energy balance of the solar lighting system, where;

- E_d- is the average daily electricity production from the given system
- E_m is the average monthly electricity production from the given system
- H_d – is the average daily sum of global solar irradiation per square meter received by the modules of the given system, kWh/ m^2, day
- E_l, is a daily load that is proportional the nighttimes hours, and the supply will be proportional to the peak sun hours.

The presented system is simulated for 0.3 kWh/day daily load value. The load patterns tend to be unbalanced throughout the day. The figure 4 shows the demand pattern of the LED street lighting system.

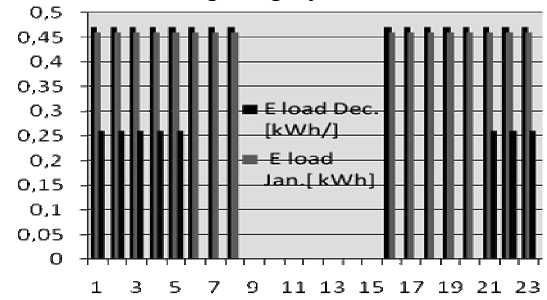

Figure 4. Load Pattern for a PV -street lamp

The loads are high usually between 5pm and 7 am in winter time and between 8 pm and 5 am in summer period. This scenario can be used in design technique of the PV street lighting system.

The PV array built with two modules connected in series generate the electricity, the instantaneous electrical energy output from the PV module is calculated using the following equation (Urme et all)

$$E_{PV} = \eta_{Array} \cdot A_{PV} \cdot I_S \tag{1.3}$$

where,

- E_{PV} is the energy output from PV modules
- η_{array} is the instantaneous array efficiency
- A_{PV} is the total area of the array and
- I_s is the instantaneous solar radiation per unit area incident on the array.

The daily available energy generated by the PV modules compared with the daily load for lighting system is presented in figure 5.

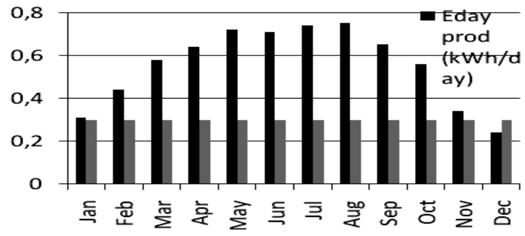

Figure 5. Comparison of daily loads, (kWh) and energy availability for lighting system.

From this figure we can be observed that the array output in winter period specially in December is lower then the necessary energy, because all other months have more daylight hours than December, In this case we can reduced the lighting time, in generally the commercial PV lamps has lower working period like the presented PV lamp unit. This manufacturer indicted 5-10 hours for 5 days autonomy of the storage unit. From this figure can be observed that in another months the energy generated by the PV array is higher then the daily loads that produced more energy that the loads can be consumed. For this one of the technical solutions is to storage the energy in battery. For the study of the battery comportment in this case, the state of charge parameter can be evaluated with helpful of commercial simulation software's; the used program is N-Sol V5. and the simulation results are represented in figure 6. (Bartha, et all)

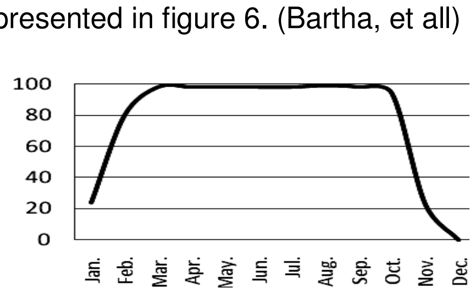

Figure 6. The SOC value of the battery

From this figure can be observed that in winter period the battery SOC is low, in this case this can be deep discharged and caused the reducing the lighting time of the lamp. The presented model has 7.5 day autonomy and the annual value of the LOLP, loss of load probability is 66.6% and the annual availability of the system is 89. 9 %. For a stand alone system the total battery capacity should be five times of the daily usage. In generally in case of commercial system 5 days of storage is used. The PV system have life – cycle greenhouse gas emission in the range of 25-35 g/ kWh, is relatively low in comparison with other energy options, that have a large application potential. If we take into account the value of the emission of carbon dioxide to produced of one kWh electrical energy in Romania is 490 g/ kWh the designer can be evaluate the equivalent amount of annual CO2, in this case study for 200 kWh annual energy production the carbon dioxide quantity is 98 kg CO2. In case of the street lighting application with 100 LED lamps this energy supplying unit reduced the CO2 emission with 98 tones.

4. Conclusion

The RES industry is now focussing a various measures which will reduce the energy consumption and has a consequential impact on budgets and carbon dioxide emissions. The presented technical solution has a positive environmental impact, reduced the energy consumption, in generally the PV technology is in a very good position to be included in a portfolio of low carbon energy technologies for a future sustainable energy supply.

The presented energy conversion system can be used successfully in supplying the LED street lighting system. The optimal type of battery for this PV lighting system is a deep-cycle battery that can be repeatedly drained of much of its energy and recharged. The maximum deep of discharged, DOD (is the inverse of the SOC) for low maintenance batteries is 30%. This value is in concordance of the SOC of the battery obtained in energy balance in winter period, predicted by the used model.

The energy balance algorithm presented in this paper can be generalised and used in preliminary planning of the stand alone PV supplying systems. For the precision design is indicated to evaluate the application site solar energy potential. In this way will be ensure a continuous operation of the street light system without brooking down of the technical unit. For the region with reduced solar energy performance we have recommended an. 170Wp PV panel and a battery of 230 Ah, the used LED lamp power is 30W. In this case the average daily lighting use in winter period is 7.7 hours. This lamp has 8Lux iluminance at 10 m suspension distance. This study opens the way for the development of the design of the performed quality street lighting system indicated to use for application with reduced solar energy potential. Applying the simulation date we can build one real prototype photovoltaic street lighting system.

5. References

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