Outdoor lighting using renewable energy sources

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Abstract: - In the past few years there is a global transformation on technology and researches which aims to energy savings through the usage of renewable sources in many applications. Solar as well as wind energy can be used for street lighting usually in cases of low consumption applications. This research aims to illuminate a low traffic road according to CIE M5 Class requirements, using only solar and wind energy. The objective is to operate the lighting system with renewable energy and also to use the appropriate lamp for the lighting of low traffic roads. According to recent studies in the mesopic region, the ideal lamp for this application is a metal halide lamp. In this study, a specific methodology is developed, which calculates the annual solar energy and the annual wind energy that the whole system needs to be autonomous. The proposed lighting system is an integrated unit with a photovoltaic panel, a wind generator, lamp, battery, inverter, charger etc. After extended calculation the appropriate parts of the system are selected in order to be autonomous. A result of system design is that an amount of the produced energy remains. This energy production can be sold, making the system a small energy producer in the connected power grid.

Key - words: photovoltaics, wind generator, renewable energy sources, outdoor lighting, street lighting, energy saving.

1 Introduction

Recent researches show that street lighting at night can be a costly and complicated matter. Issues such as, no available grid power or expensive trenching and cabling requirements can prevent adequate lighting being installed. An indicated solution is street lighting using renewable energy, solar and wind. With very low maintenance these solar-wind streetlights will pay for themselves. Many applications have been made especially the last decade round the world [1-6]. In countries such as USA, UK, Italy several PV street lighting projects have been carried out in order to save energy. In Greece many efforts have been made for the expansion of this technology, but still the results are not very satisfactory. The applications are limited in building projects, but the need of cheap and clean energy, especially in Greece where is observed high amount of sunlight and wind, have lead to the realization of projects of street lighting, but in experimental level yet.

This case study develops a method to illuminate a road by using a system which combines energy production from wind generator (WG) and photovoltaic (PV) panel. The complete system, apart from a PV system, a WG and a luminaire, is mounted on a single pole. At the beginning is considered the solar radiance that cascades to the panel and the wind speed that can operate the WG. This permits the selection of the suitable PV panel and WG. The other important devices of the system as the charger, the battery, the control unit and the inverter are also determined. Further calculations determine the total power production of the system, the consumed energy for street illumination and the remained energy.

2 Measurement of the Wind Speed and Solar Radiation

The solar radiation and the wind speed are key data for the calculation of the output energy of the proposed system. There are many historical data for the solar radiation and wind speed as well as other meteorological data available in national services and others. For this study all the needed data was collected through the meteorological service on the National Technical University of Athens (NTUA METEO). This service records the solar radiation and wind velocity 24 hours/day, using the appropriate equipment, every day, throughout the year in the urban area of Athens. For the purpose of the project the measurements of a full year were used (January-December with the time interval of 10 minutes).

An application in Visual Basic was created in processes all the measurements. The outputs of this algorithm were the annual distribution of solar energy measured on horizontal surface and the annual wind speed at 6m height (Fig. 1 and Fig. 2). All the measurements of solar energy and wind speed were recorded in a point inside the urban area similar to places where the proposed system is designed to be installed.

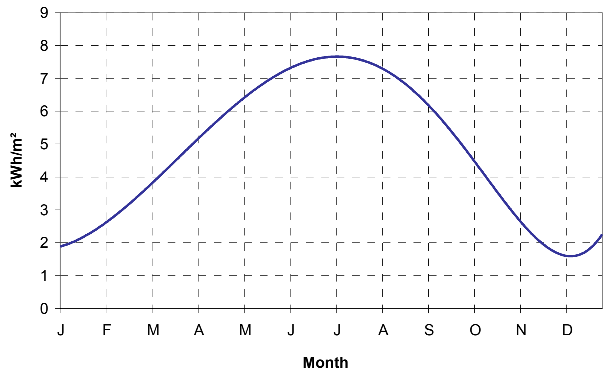

Fig. 1 – Annual distribution of solar radiation in urban area of Athens (horizontal surface).

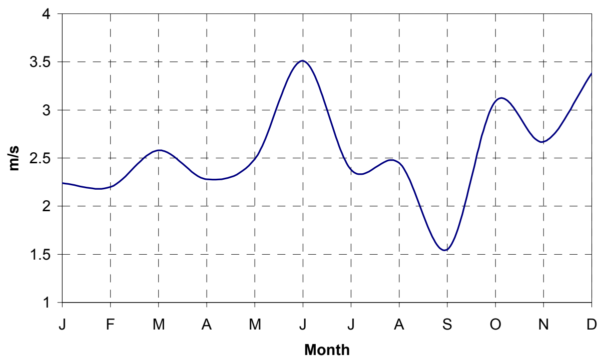

Fig. 2 – Annual wind speed in urban area of Athens (at height of 6m).

3 Transformation of the measurements

The pyranometer measures solar radiation at the horizontal level, so the diagram on Fig. 1 shows the daily solar energy that prostrates on the horizontal surface. For different angles of the surface the solar radiation that prostrates varies. A specific method is used, in order to calculate the solar radiation on tilted surfaces. This method transforms the solar radiation values from horizontal surface to tilted surface as shown below. The daily solar radiation on a tilted surface (H_t) is:

H_t = (Solar beam component + Sky diffuse component + Surface/Sky reflectance component)

or

$$H_t = (H-H_d)R_b+H_d\ ((1+\cos\beta)/2)+H^*\rho_s((1-\cos\beta)/2)$$

where

H: solar radiation measurements (pyranometer)

β: angle of the PV panel relative to a horizontal surface (varies from 0^o to 90^o)

ρ_s: surface reflectance (=0.2)

$R_b=(\cos(\varphi-\beta)\cos(\delta)\sin(\omega_{ss})+(\omega_{ss})\sin(\varphi-\beta)\sin(\delta))/(\cos(\varphi)\cos(\delta)\sin(\omega_s)+\omega_s\sin(\varphi)\sin(\delta))$

φ: latitude (=38^o for Athens)

δ: solar declination (=23.45sin(2π((284+n)/365))

$\omega_s = \cos^{-1}(-\tan(\varphi)\tan(\delta))$

$\omega_{ss} = \min(\omega_s, \cos^{-1}(-\tan(\varphi-\beta)\tan(\delta))$

$H_d = H(1.391-3.569K+4.189K^2-2.137K^3),\ \omega_s<81.4^o$

$H_d = H(1.311-3.022K+3.427\ K^2-1.82K^3),\ \omega_s>81.4^o$

K: Ratio of solar radiation at the earth level to the radiation before entering the atmosphere

Using these equations, it is calculated the solar radiation H_t on titled surfaces for various angles (Fig. 3). The orientation of the PV panel is south.

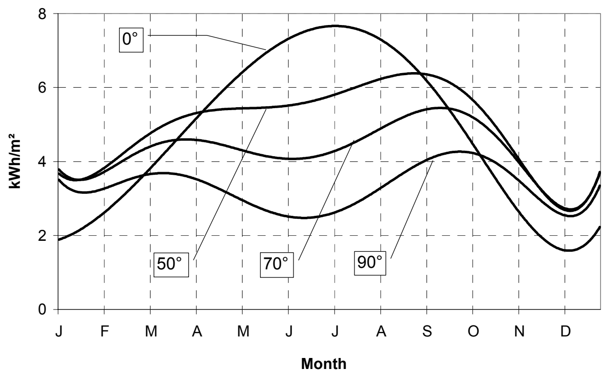

Fig. 3 – Calculated annual distribution of solar radiation on tilted surfaces.

As mentioned the measurements of the wind speed was at 6m height. According to calculations the WG of the proposed system will be fixed at 11m height. For this a transformation of the values was needed. The formula for the transformation is:

$$U(Z)/U(H)=\ln(z/z_0)/\ln(H/z_0)$$

where:

U(H): The measured value at 6m height

U(Z): The calculated value at 11m height

z: height above ground level for the desired speed

z0: roughness length in the current wind direction

The calculated values of wind energy and the height of 11m are shown on Fig. 4.

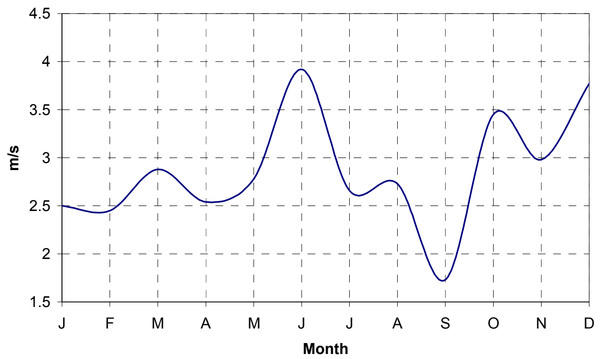

Fig. 4 – Calculated annual wind speed (at 11m)

4 System

The proposed system consists of a PV panel, a WG, a charger, a storage device, an inverter, a luminaire and a control unit (Fig. 5).

The selection of the solar panel and the WG was made after the calculation of the total consumption of the luminaire plus the losses of the inverter (10%) and the losses of the battery (14%). The total consumption of the system is 55.5 W.

The characteristics of all the system parts are in Table 1.

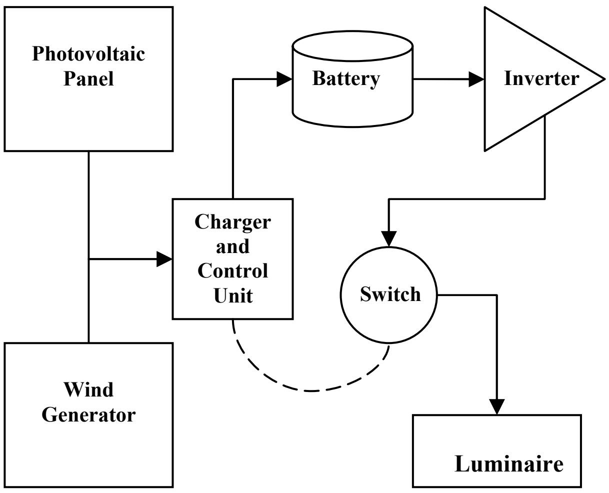

Fig. 5 – Block diagram of the system.

The selected solar panel is a SIEMENS SM100 (Fig. 6) with rated power 100Wp. It is obvious that the PV panel must be fixed on the pole, over the luminaire, in a suitable angle so as to collect the most energy at winter period and also enough energy at summer period. After calculation and examination, for all possible PV panel tilt angle, the appropriate angle appear to be 50° (south orientation). The selected WG is an AIR403 (Fig.7), low weight, suitable for fixing on the top of the pole. The mean capacity factor of the WG as it calculated is 0.07 (or 7%). This happen because the generator will operate in an urban area where annual wind speed is much lower than the nominal. This means that the proposed system is designed to be autonomous when it will be installed in an urban area. On a different area of installation (e.g. at the borders of the urban area or outside of town) the system will produce more energy. The battery, the inverter and the other part of the system will be placed on the base of the pole, inside a container, in order to be protected from the weather conditions.

Table 1 – System's parts characteristics.

PV panel	SIEMENS SM100 – 100Wp
Wind Generator	Air 403 – 400W at 12.5m/s
Lamp	Philips CDM-T 35W
Luminaire	Philips, Iridium SGS 252 GB
Battery	PowerSonic 24V- 100Ah
Inverter	Compa KV 150W
Charger	Steca PR 24V/10A

Fig. 6 – The selected photovoltaic panel (SIEMENS SM100).

Fig. 7 – The selected wind generator (AIR 403).

The total energy consumption of the system depends on the time the luminaire must illuminate the road. The operation schedule of street lighting is scheduled by the Public Power Corporation of

Greece. The proposed system is designed to follow the schedule with the control unit. This unit monitors the charging of the battery by the PV system and the WG and operates the luminaire according to schedule.

The calculated daily energy consumption of the lighting system according to time schedule is shown on Fig. 8.

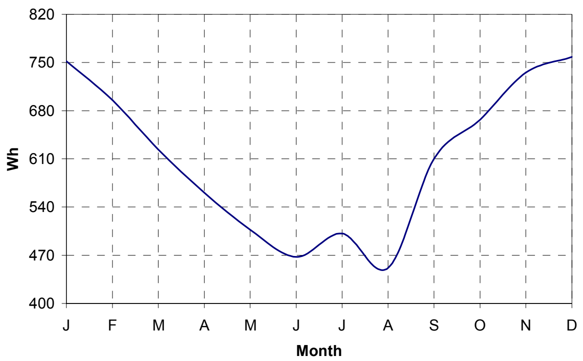

Fig. 8 – Calculated daily energy consumption

5 Lighting System

For the purposes of this investigation, a common road with two lanes is used. Due to the limited potential of the proposed system, a low consumption lamp with high efficiency is needed. The most commonly used types of lamps for street lighting are: low and high pressure sodium, mercury vapour and metal halide. From these types the metal halide was found to be the more suitable especially due to recent researches showing that their spectrum approaches better the mesopic vision [7].

The optimum combination of luminaire/lamp was found after several lighting calculations on the same type of road. It is a Philips SGS luminaire with a CDM-T 35 W metal halide lamp (Figs. 9, 10).

Fig. 9 –Selected luminaire (Philips, Iridium SGS 252 GB CR CT-POT) [8].

The calculation of the lighting installation has been performed using Philips Calculux Road 5.0. The calculated lighting parameters (illuminance and luminance) as well as the technical characteristics of installation are presented in Table 2.

Fig. 10 – Selected lamp (Philips, CDM-T35W) [8].

The low power potential of the system requires an efficient installation. Therefore a rather high maintenance factor is essential. The value of 0.85 for the maintenance factor is acceptable, given that the selected luminaire is of IP 65 type. However such an installation requires regular maintenance.

Table 2 – Characteristics of lighting installation.

Luminaire type		Philips Iridium SGS 252 GB CR CT-POT P.5
Lamp		Philips CDM-T35W/830
Lamp output		3300 lumens
Ballast		Electronic
DLOR		0.84
ULOR		0.00
TLOR		0.84
Total Power		44 W
Carriageway		Single carriageway
Road width		6 m
Reflection table		Asphalt CIE R3
Installation		Staggered
Height		7.00 m
Spacing		22.00 m
Overhang		0.50 m
Tilt 90°		5.00 °
Overall Maintenance Factor		0.85
Luminance	Average	0.56 cd/m²
	Maximum	0.75 cd/m²
	Min/average	0.54 cd/m²
Illuminance	Average	8.60 lux
	Maximum	14.60 lux
	Min/average	0.57 lux
Surround ratio	Left	0.51
	Right	0.51
Threshold increment (TI)		12.70 %

The calculated illuminance and luminance distributions of the road under consideration are shown in Figs. 11 and 12. It should be noted that the all calculated values meet the requirements of CIE No.132 international standard for a typical low traffic road of M5 class [9].

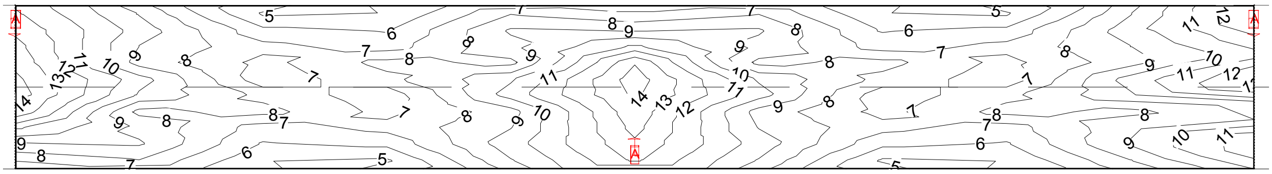

Fig. 11 – Illuminance calculation (Philips Calculux Road 5.0)

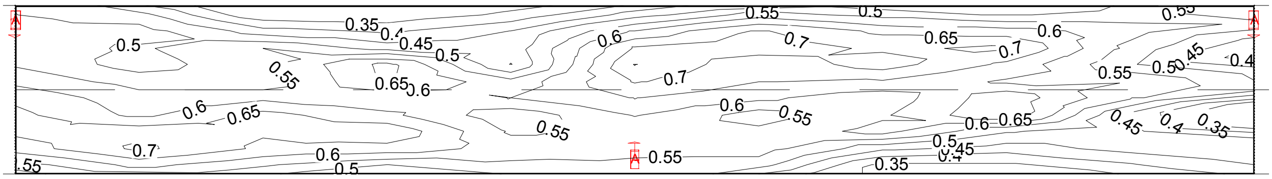

Fig. 12 – Luminance calculation (Philips Calculux Road 5.0)

6 Produced Energy

The produced energy from the proposed system is calculated as the sum of energy produced from the solar panel and the WG. All losses have been calculated and excluded from the generated energy. The total energy production is shown on Fig. 13. In the same diagram is also included the energy that the lighting system consumes. In summary the annual energy production of the system is 371,7 kWh while the annual consumption is 222.8 kWh.

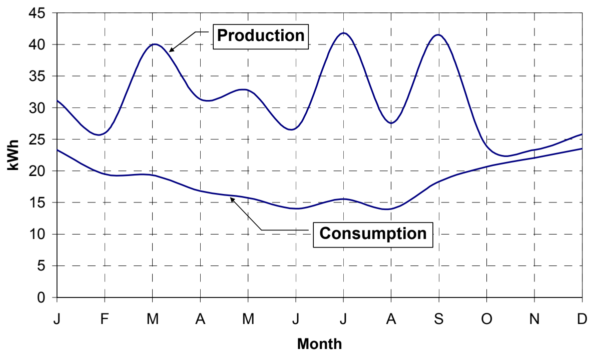

Fig. 13 – Annual energy produced and consumed

The energy that remains from the production can be sold to the power utility as the system is designed to be connected to the power grid. The calculated annual remain energy is 148.9 kWh. The distribution of the remained energy that can be sold is shown on Fig. 14.

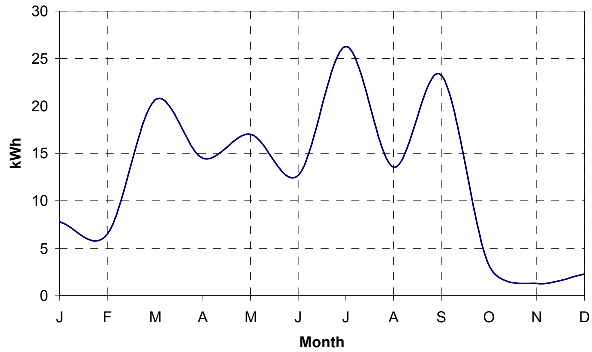

Fig. 14 – Annual remaining energy for dispatch

It is obvious that the energy that exceeds every day varies in the period of one year. At summer moths remains more energy that at winter moths, where in some cases the produced energy is almost equal to energy that the lighting system need for full-time operation. This happens because the system is designed to produce enough energy for whole year in order to operate alone in places where connection to grid is difficult or impossible.

7 Conclusions - Remarks

The proposed system is designed to be full autonomous through the whole year. The calculated energy production is 371.7 kWh while the annual consumption is 222.8 kWh. The remaining 148.9 kWh can be sold given that the system is connected to power grid. In the other hand if the system works stand-alone the produced power is enough for the autonomous operation.

The lighting system of this application is most appropriate for lighting of low traffic roads. According to recent research works the metal halide lamp is suitable for mesopic vision lighting. There are many other combinations of luminaries that can be used in any cases of lighting.

One of the most important factors for the system efficiency is the location of the pole. In case that a pole is surrounded by high buildings or trees, which prevent the sunlight to reach the PV panel, the output of the system will be lower. The panel should be free of dust, pollution and other pollutants by regular maintenance. Also the place where the system is place can influence the power generation of the WG. All these factors may change the total power output day by day.

The main objective of the system is the energy saving. This paper examined such a system that illuminate a low traffic road with clean energy for 100% of the annual operation time. If the proposed method is widely implemented, the savings are considerable, compared to the total energy consumption of street lighting.

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