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Sizing of PV Based LED Lighting System Considering Minimum Solar Radiation Level

[Ali Ajder, Hakan Akca, Huseyin Akdemir, Ramazan Ayaz, Ismail Nakir and Mugdesem Tanrioven]

Abstract— **Solar- LED outdoor lighting system allows governments to illuminate remote areas without electric network. For these systems a battery is required to store energy from PV panel during the sunshine and supply the LED light during the night. This paper presents simple analytic procedure for optimal sizing of PV panel- LED light and battery combination considering radiation data. Real meteorological data are used in MATLAB to calculate system components capacity. After that, stand-alone and grid connected solar- LED system is presented in terms of optimum tilt angle and amount of surplus energy. Finally, the PV panel is oriented at optimum tilt angles for seasons and compared with energy which is obtained at annual optimum tilt angle.**

Keywords—Battery sizing, LED outdoor lighting, Optimum tilt angle, Photovoltaic systems

I. Introduction

At the present time, ergonomic design and secure are important lighting parameters in daily life. When the light is determining for our needs, we should consider about cost, energy saving and environmental factors.

A good light definition should contains satisfaction, electrical performance, comfort, green effect, energy saving, functionality, color rendering, lighting level, contrast, distribution, and safety. Also, a lighting system should pay its cost back during life time [1].

In outdoor lighting system, metal halide lamps, mercury vapour lamps, or high pressure sodium vapour (HPSV) lamps could be used in the past [1], but there are some disadvantages of them. For example, the main drawbacks of HPSV lamps are low lifetime, poor colour rendering index (CRI), high maintenance cost etc [2].

Nowadays with the development of LED technology, LEDs are used in various lighting applications. LED lights obtained an essential market share in lighting market by replacing conventional discharge lamps because of their above mentioned disadvantages. LEDs have a lot of advantages over traditional light sources including lower energy consumption, long lifetime, smaller size, better controllability, and good CRI etc [2]. In addition to this, the compatibility of LEDs with PV systems is significant for energy efficiency and environmental factors.

In PV-battery and LED systems, the battery is fundamental, since solar energy is stored during the daytime and it is used after the sunset until the dawn. In other words, in this systems the primary sources is solar energy and it charges the battery. The secondary sources is the battery which supplies the LEDs demand at night [2].

An essential parameter in order to obtain maximum solar energy for solar systems is the optimum tilt angle of PV panels but for this types of application (PV-battery-LED) the maximum amount of energy may not be very important when determining optimum annual tilt angle. Because in winter solar energy is the lowest level in north hemisphere and it is more significant to supply LED light energy in winter months. It is not aimed to storage the surplus energy in summer, also the purpose is to supply the LEDs demand for a year with an optimum PV-battery solution.

This paper explains sizing of PV modules and battery capacity for a LED lighting. A stand-alone and grid connected solar based LED system is compared in terms of optimum tilt angle and amount of surplus energy for seasons.

II. System Design

Renewable energy sources can be used on standalone systems to generate the electricity. Especially, PV systems may be a good alternative for these systems. However for maximum cost reduction, reliability and efficiency, determining components capacities is vital in Stand-alone PV lighting system [3]. Solar and storage technology are advancing all the time, and optimizing PV module and battery capacity turn out to be more difficult tasks.

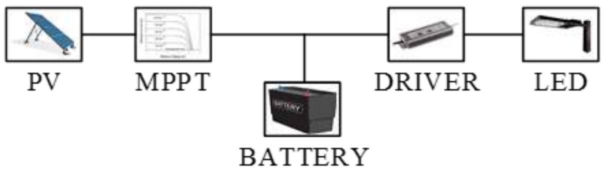

Figure 1. PV based LED lighting system block diagram.

In *Fig. 1*, PV module generates electricity from solar radiation during the day until sunset. The battery storages the energy and it supplies LED when sundown. Also there is a MPPT charge controller to produce maximum energy from the PV model throughout the day. A 40W LED is approved for outdoor lighting and it is assumed by a resistor. Therefore, it is significant to emphasize that the current of lamp is constant.

PV-battery system supplies the lamp energy demand even minimum radiation level, so the system does not performance its full capacity in greatest quantity of the year. Although the stand-alone PV-lighting system has a high cost initial investment compared to conventional grid connected lighting systems. There is an essential development on LED and storage technologies because of this reason, initial cost would be reduced in next years.

If the system is not optimized properly, the surplus energy changes from 5% to 30% of load per day on standard weather conditions in a year[3]. Taking into account all of

Ali Ajder, Hakan Akca, Huseyin Akdemir, Ramazan Ayaz, Ismail Nakir and Mugdesem Tanrioven
Yildiz Technical University
Turkey

these, the calculation of enow energy is important for optimization.

In the next section, all equipment of the system is investigated with technical requirements for system optimization.

A. *Selecting of Lamp*

At the present time, gas-filled lamps are used in most of the exterior lighting system application. These lamps have 12000 hours lifespan approximately. Although LED lamps are twice as high-cost as conventional gas filled lamps, they have about 50000 hours lifetime[3]. Due to the continuous improvements in LED technology, the price of these lamps is expected to decrease gradually. Furthermore, LED lamps allow lighting designer for more decorative application options due to their small size. There is a basic comparison between these outdoor lighting lamps in terms of efficiency factor, lifetime and CRI in *TAB. I*.

TABLE I. THE BASIC COMPARISON OF LAMPS TECHNICAL SPECIFICATIONS.

	Efficiency Factor[lm/W]	**Lifetime [hours]**	**Colour Rendering**
Metal-halide Lamp	72-110	6000-12000	good
Low Pressure Sodium-Vapor Lamp	100-192	16000	very bad
High Pressure Sodium-Vapor Lamp	88-130	16000-32000	bad
Light Emitting Diode (LED)	90-150	25000-50000	good

As is seen in *TAB. I*. LED lamps have higher efficacy factor and lifetime. Another important point is that, LEDs can be produced with different colour temperatures. So, it is possible obtaining of a good CRI. Because of these advantages, LEDs may be preferred on alternative energy systems.

B. *Battery*

The determination of optimum sizing of the battery obligates a detailed analysis of the battery's charge and discharge requirements. The different types of battery can be selected for specific application. Therefore, it is essential to consider battery types, ambient temperatures and the number of cells in the battery.

In this system, it is important to store the energy during the hours of sunshine whereas electrical energy is required after the sunset. Therefore, it is significant to have long battery life which is closely connected with the maximum depth of discharge (M_{DoD}). M_{DoD} is in general restricted to 70% [4]. The battery capacity calculated as in Equation (1).

$$E_b\ (Ah) = \left(\frac{P_T}{\eta_b\ x\ M_{DoD}\ x\ V_b}\right) x\ D \qquad (1)$$

D is the number of autonomous days which is significant for sizing of battery capacity. η_b and V_b represent charging/discharging efficiency of the battery and operating voltage of battery, respectively.

C. *PV module*

Nowadays the amorphous, the polycrystalline and the monocrystalline silicon technologies are used for commercialized PV systems. The amorphous has poor efficiency (about 6%). The monocrystalline technology attains 15% consequently has high-cost. The polycrystalline is frequently preferred in many PV system applications because of its lower cost meanwhile it has higher efficiency (about 10%) than the amorphous[5].

In a typical PV lighting application, PV panels and batteries are optimized for worst solar irradiation.

Measurements of the diffuse irradiance on the horizontal surface are not available though there are recorded only global radiation data by many meteorological stations. However, diffuse component of the global radiation is also required to determine the incident radiation on inclined surface. Firstly, the radiation on the horizontal surface is separated into its components; direct and diffuse, as can be seen in Equation (2)[6].

$$I_{GLOBAL} = I_{DIRECT} + I_{DIFFUSE} \qquad (2)$$

Then in Equation (3), direct, diffuse and reflected components of global radiation is obtained for inclined surface using on horizontal surface radiation[7].

$$I_{total} = I_{direct} + I_{diffuse} + I_{reflected} \qquad (3)$$

Fig. 2 illustrates components of global radiation on inclined surface.

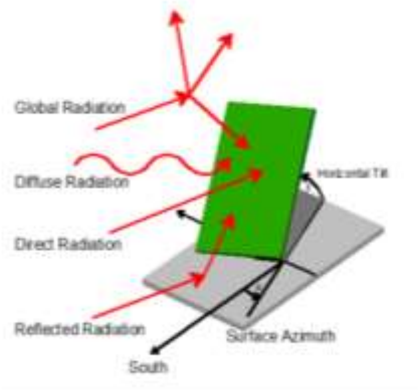

Figure 2. Components of global radiation on tilted surface.

III. Results

A. *Energy Requirement for LED Light*

In this system, a 40 W LED light can be used for a pole in a park. A driver is required to operate a LED module and its efficiency is $\eta_d = 0{,}95$ [3].

In order to calculate energy demand, night hours for Istanbul are given in *TAB. II*.

TABLE II. NIGHT HOURS IN A YEAR. [HOURS]

Winter	*Spring*	*Summer*	*Autumn*	*Total*
1244	941	810	1121	4116

The percentage of LED light operation hours for a year is presented in *Fig. 3*.

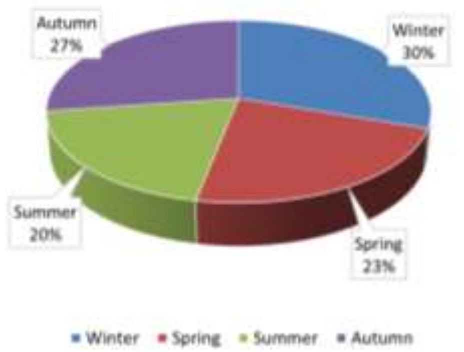

Figure 3. Percentage of LEDs operation hours in terms of seasons.

Average solar radiation data in 2004 for Istanbul and average solar radiation in Turkey [8] are shown in *TAB. III.* Hourly solar radiation (year 2004) for Istanbul is used to calculate for seasonal energy output.

TABLE III. SEASONAL AMOUNT OF RADIATION.[KWH/M²-DAY]

	Winter	Spring	Summer	Autumn	Total
2004 (Istanbul)	1.63	4.3	5.76	2.67	14.36
1966-1982 Average (Turkey)	1.8	4.05	5.46	3.01	14.32

It can be seen from *TAB. II.* that maximum operation time of LED light is in winter. Minimum radiation level is also in this season (*TAB. III*). For this reason, optimum tilt angle of PV panel has to be adjusted for winter.

Total energy demand of LED light and driver in winter is calculated with Equation (5).

$$E_{Win.} = \frac{P_{LED} x\ t_{Win.}}{\eta_d} \quad (5)$$

$$E_{Win.} = \frac{40\ x\ 1244}{0,95} = 52.379\ kWh \quad (6)$$

From the Equation (5), seasonal energy requirement is calculated for other seasons which is given in *Fig. 4*.

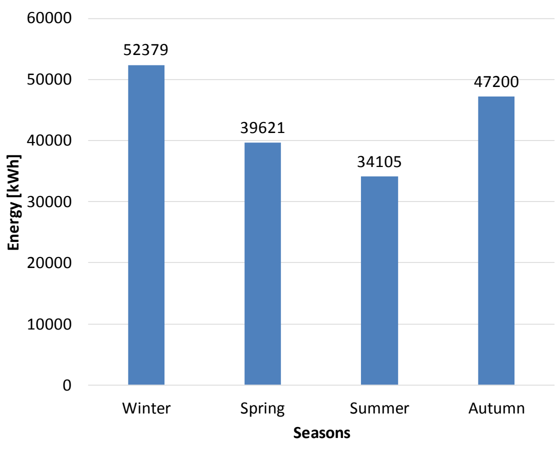

Figure 4. Seasonal total energy requirement of LED and driver.

B. *Battery Capacity*

It can be calculated from *TAB. II.* that average operation hour of LED light per day in winter using Equation (7).

$$t_{LED} = \frac{1244}{90} = 13.8\ h\ (Avg. in\ winter) \quad (7)$$

Total energy demand of LED light and its driver is calculated as 52.379 kWh for winter in Equation (6). Lead acid battery efficiency is assumed to be around 0.85 and number of days of autonomy (D) is 3 days[4]. Energy requirement for battery is obtained from Equation (8).

$$E_b\ (Ah) = \left(\frac{P_T}{\eta_b\ x\ M_{DoD}\ x\ V_b}\right) x\ D\ (h) \quad (8)$$

$$E_b(Ah) = \left(\frac{41,73}{0.85\ x\ 0.7\ x\ 24}\right) x(3x13,8) = 120.98(Ah) \quad (9)$$

It is seen in Equation (9), battery can be selected 24 V, 120 Ah.

C. *Sizing of PV Module*

Total energy output is calculated by using Matlab codes for seasonal and annual optimum tilt angle. This part of study is realized for winter which has minimum solar radiation. To find out the maximum energy output, PV panel tilt angle is changed from 0^o to 90^0[9]. As a result, the optimum tilt angle is attained as 46^0 for winter.

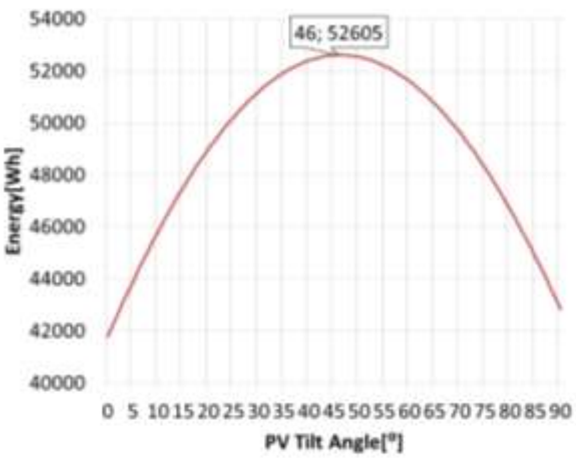

Figure 5. Varying of energy output different tilt angle .

As can be seen in *Fig. 5.* energy output is 52.605 kWh which is enough for operating of the LED during winter when MPPT efficiency is considered about 0.95[10]. In recent years, considering researches on PV Technologies, the efficiency of PV module is selected 21% [11] and the size of PV panel is calculated as 1.43 m^2 using Matlab codes.

D. *Comparison of the Worst Case and Yearly Energy Generation*

The sizing of PV panel was optimized for winter which is 'worst case' from the point of global radiation level in previous section.

In previous part, sizing of system has been carried out for the worst case. As a result, PV panel at 46^0 optimum tilt angle produces energy which is enough for requirement of the LED.

Fig. 6. shows that if PV panel optimum tilt angle is adjusted for annual maximum energy generation (26^0), annual energy output is higher than orientation of PV panel in winter (46^0). It should be emphasized that if the PV panel is oriented at 26^0, 50.443 kWh energy is generated and this value is insufficient for operating LED in winter.

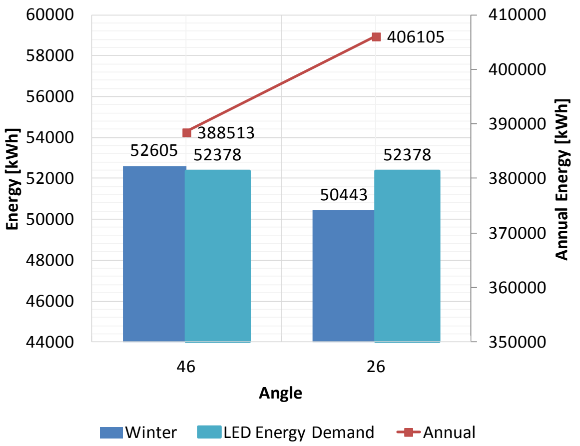

Figure 6. Comparison of yearly and winter energy output.

If it is examined grid connected PV system instead of stand-alone, orientation of PV panels would be adjusted for maximum energy output. Considering values in *Fig. 6.*, positioning PV tilt angle at 26^0 has 4.53% more energy output than at 46^0.

E. *Determination of PV Panel Tilt Angle According to Seasons*

PV panel-battery and LED system is sized only one LED light in previous sections. Assuming a lighting system which contains many LED luminaries, a centralized-grid connected PV panel system can be designed. For this system PV panels tilt angle can be adjusted for maximum energy based upon seasons. *Fig. 7.* illustrates changing of maximum energy outputs for each season depending upon PV panel tilt angles 0^o to 90^0.

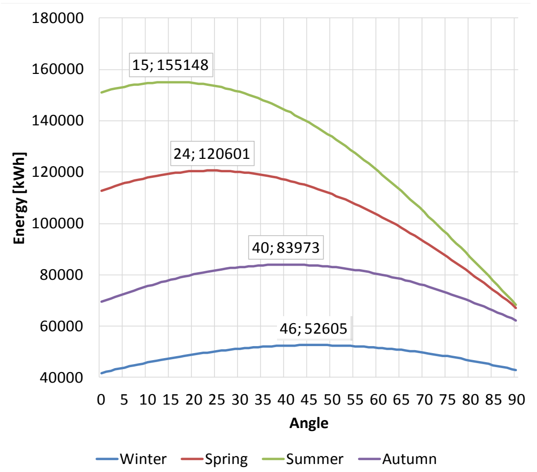

Figure 7. Seasonal and yearly energy output for different tilt angles.

Seasonal and annual energy outputs are given detailed in *TAB. IV.*

TABLE IV. ENERGY GENERATION FOR DIFFERENT ANGLES. [KWH]

	Winter	Spring	Summer	Autumn	Yearly
46	**52605**	113952	138290	83666	388513
24	50000	**120601**	153752	81513	405867
15	47525	119484	**155148**	78092	400249
40	52399	116995	144122	**83973**	397488
26	50443	120541	153043	82078	**406105**

As can be seen in *Fig. 8.* there is a surplus energy on grid connected systems. Total energy production is 412.327 kWh for seasonal orientation of PV panel. If the PV panel is oriented at yearly optimum tilt angle, total annual energy value is 406.105 kWh. The value of surplus energy of PV panel oriented for seasons is 1.53% more than positioned for annual.

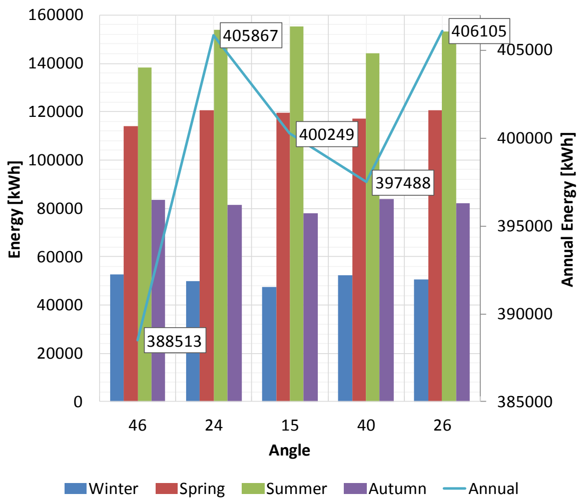

Figure 8. Comparison of energy generation.

Therefore, a fixed-oriented system can be an economic choice because for seasonal oriented systems need extra equipments and cost to change tilt angle. On a fixed system, there is no extra need because of constant tilt angle.

IV. Conclusion

In this paper, simple analytic procedure is presented for optimal sizing of PV panel- LED light and battery combination considering radiation data.

Firstly, outdoor lights are evaluated considering their electrical and optical performance. LED light is selected because of improvement of LED technologies. The battery which supplies energy requirement of LED is determined based upon the worst case (in winter). The PV panel is sized to supply electricity demand of the LED during winter and PV panel is calculated as 1.43 m^2 using Matlab codes.

Secondly, the worst case and yearly energy generation are compared then it is showed that positioning PV tilt angle for annual has 4.53% more energy output than orientation for winter.

At the end of the study, on the grid connected systems, the value of surplus energy of PV panel oriented for seasonal optimum tilt angles is 1.53% more than fixed-positioned for annual.

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About Author (s):

Ali Ajder received the M.Sc. degree in Electrical Engineering from Yildiz Technical University, Turkey, in 2011. Now, he is currently working toward the Ph.D. in same department. His research interests include energy economy, renewable energy and lighting.

Hakan Akca received the M.Sc. degree in Electrical Engineering from Yildiz Technical University, Turkey, in 2011. Now, he is currently working toward the Ph.D. in same department. His research interests include power converters, renewable energy and lighting.

Huseyin Akdemir received the B.Sc. degree in Electrical Engineering from Yildiz Technical University, Turkey, in 2014. Now, he is currently working toward the M.Sc. in same department. His research interests include renewable energy and motor control.

Ramazan Ayaz received the M.Sc. degree in Electrical Engineering from Yildiz Technical University, Turkey, in 2012. Now, he is currently working toward the Ph.D. in same department. His research interests include renewable energy and lighting.

Ismail Nakir received the PhD. degree in Electrical Engineering from Yildiz Technical University, Turkey, in 2012. Now, he is with the Electrical Engineering Department of Yildiz Technical University, Turkey. His research areas include PV System, Maximum Power Point Trackers.

Mugdesem Tanrioven received the PhD. degree in electrical engineering from Yildiz Technical University, Turkey, in 2000. Now, he is with the Electrical Engineering Department of Yildiz Technical University, Turkey. His research areas include renewable energy, power system reliability.