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doi:10.15199/48.2018.01.39

Technical & economical evaluation of solar powered LED street lights: An overlook contributor to load-shedding

***Abstract**. The traditional Street Lighting System (SLS) in Pakistan is based on mercury and sodium-vapor lamps. The individual lamp in SLS consumes 60 W to 600 W from the utility system. This increased power consumption ultimately affects the commercial and residential consumers thereby causing load-shedding during the peak hours. To reduce the power consumption and to shed some load from utility network, solar powered Light Emitting Diode (LED) Street lighting system has been suggested by the ministry of planning and development of Pakistan across the country. The LEDs with an equal luminance of 72 lm/w comparing to 250 W sodium-vapor or mercury lamp consume 100 W. Since the capital cost of installing solar powered LED lighting system is higher than traditional lighting system. But on the long term planning scale, the results are very much promising, resulting in 60% saving of energy. To evaluate the technical and economical feasibility of solar powered street lighting project, this research investigates the performance and installation cost of LEDs based SLS in the urban region of Sindh, Pakistan, with two lanes having pole distance of 30 m. This study shows that the total cost of installing the solar powered LED SLS is 21.25 million PKR and 13.98 million PKR for utility powered LED SLS as compared to 5.48 million PKR for traditional SLS, except electricity charges. On average, the deployed traditional SLS consumes 547,500 kWh/yr. The payback time for suggested solar powered LED lighting system is 5.384 years. The reliability and efficacy of results were assured through HOMER software.*

Streszczenie.** Tradycyjny system oświetlenia ulicznego (SLS) w Pakistanie oparty jest na lampach rtęciowych i sodowych. Poszczególna lampa w systemie SLS zużywa od 60 W do 600 W od systemu uzdatniania. To wzmożone zużycie energii wpływa ostatecznie na konsumentów komercyjnych i mieszkalnych, powodując w ten sposób spadek obciążenia w godzinach szczytu. Aby zmniejszyć zużycie energii i rozładować niektóre obciążenia z sieci energetycznej, zaproponowano ministerstwo planowania i rozwoju Pakistanu w całym kraju, system oświetlenia ulicznego LED emitowanego przez energię słoneczną. Diody LED o tej samej luminancji 72 lm / w w porównaniu do lampy sodowej lub rtęciowej 250 W zużywa 100 W. Ponieważ koszt kapitału zainstalowania systemu oświetlenia LED jest wyższy niż w przypadku tradycyjnego oświetlenia. Jeśli chodzi o długoterminową skalę planowania, wyniki są bardzo obiecujące, co daje 60% oszczędność energii. Aby ocenić techniczną i ekonomiczną wykonalność projektu oświetlenia ulicznego zasilanego energią słoneczną, przeprowadzono badania dotyczące wydajności i kosztów instalacyjnych lamp SLS w rejonie miejskim Sindh, w Pakistanie, z dwoma pasami o odległości bieguna 30 m. Badanie wykazało, że całkowity koszt zainstalowania zasilanego energią słoneczną LED SLS wynosi 21,25 mln PKR i 13,98 mln PKR dla zasilanych energią elektryczną LED SLS w porównaniu do 5,48 mln PKR dla tradycyjnych SLS, z wyjątkiem opłat elektrycznych. Średnio, wdrożony tradycyjny system SLS zużywa 547 500 kWh rocznie. Czas zwrotu energii dla sugerowanego systemu oświetlenia LED wynosi 5,384 lata. Niezawodność i skuteczność wyników została zapewniona dzięki oprogramowaniu HOMER. **Techniczne i ekonomiczne aspekty ośiwtlenia ledowego ulic

Keywords: LED Lamp, Solar Power, Street Lighting System (SLS), Lithium-Ion Battery, Energy Saving, HOMER software
Słowa kluczowe: Lampa LED, energia słoneczna, system oświetlenia ulicznego (SLS), bateria litowa, oszczędność energii, oprogramowanie HOMER

Introduction

The issue of daunting energy crisis and load shedding in Pakistan are severely affecting its economy. The present power generation in Pakistan from all the sources is 24, 830 MW with a shortfall of over 4500 on a regular basis with routine power cuts of up to 6 hours per day [1]. This eventually has shed an estimated 2.5% off its annual GDP. The net solar power production in Pakistan is 2,500 MW which is around 10%, and is expected to reach 6,500 MW in 2030 [2]. Since the Pakistan has great amounts of its own renewable energy sources to meet up the energy needs of whole country especially in the solar sector. The solar irradiance in Pakistan is 5.3 kWh/m^2 per day[2]. The new undergoing energy projects under the China- Pskistan Economic Corridor (CPEC) have strengthened the use of renewable energy sources of Pakistan for power production.

With the recent boom of energy in Pakistan under CPEC projects, the ministry of planning and development of Pakistan has suggested the use LED lighting system in the streets and at the highways to the save the energy and cost [3]. The solar-powered LED for roadway lighting requires a proper design with suitable installed capacity of solar module and lithium battery according to the power requirements of installed LEDs based SLS [4]. LED will reduce the power consumption and as well as the saves the utility power, which can be used for other commercial uses [5].

Since the conventional SLS in Pakistan uses sodium-vapor lamps which usually consumes 250 W per lamp in order to meet the streets and highways standard lighting demand. But the LED with an efficacy of 72 lm/W consumes less amount of power up to 100 W with same lighting demands. The LED based SLS also implies the least utilization of copper wires. Since for the stand-alone solar system, the cost of transmission is null. These two main factors contribute towards the economic evaluation of LED based SLS in Pakistan.

Recently many studies have been carried on the feasibility of introducing the solar system to the SLS. Huang et al. (2007) investigated the design of solar powered LED lighting systems on the highways. They evaluated the cost estimation of installing the project and finds that it eventually saves 75% of the energy as compared to the mercury lamps [6]. Lina et al. (2015) studied the uses of LEDs in the public sector lighting system in Jordan. They analyzed the economic feasibility of roadway lighting system stretched out to 2 Km length with LEDs rated at 110 W [7]. Tsado et al. (2012) proposed a comparative analysis of street lighting powered by public electricity utility and through solar energy in Nigeria [8]. They calculated the payback time of 20 years for suggested project in order to become economically feasible [8]. Xumei et al. (2007) investigated the performance of solar powered city Rizhao in China [9]. They found that, in addition to residential and commercial buildings, the most of the signals and street lights were also powered through solar power system. They concluded that the achievement of project is the result of government policy, local solar industries that seized the opportunity and the geo-graphical logical of the city [9]. Kumae et al. (2015) discussed the replacement of sodium vapor lights with LEDs at the industrial zones in India. They analyzed the size and performance of each component of

solar street light project and proposed the economical solution for deploying such projects [10].
This research work carries out the energy saving analysis of conventional SLS and proposed solar powered LED based SLS. The economic feasibility of the solar powered LED based SLS for 5 Km highway with 2 lanes and 25 m pole distance is then studied. The Economic comparison of all the three possibilities for SLS, namely, LED based SLS powered by utility network, LED based SLS powered by solar panels and the conventional sodium-vapor based SLS, is carried out.

Design & workin of Solar Lighting System (SLS)
The solar street lighting system uses solar panels to convert sun energy into electrical form, which is then stored into batteries. [11] The batteries get charged during the day time and discharge during night time, to lightening up the street lamps, when sun is unavailable. Sensors are being installed to make the operation automatic [12]. Theses sensor detects the sun lights, and turn off the lamps and during the night time, turn them on accordingly. The street lighting system has following essential components, also shown in figure. 01. The heart of street lighting system is solar panel, which converts solar energy into electricity. Lighting fixtures are used to support and mount the lamps. The rechargeable battery is used to store the charge during the day and supply to lamps during the night time. The charge controller is used to maintain the voltage values at the terminals of battery and to regulate the charge flow to lamps. The poles are used to erect the entire system on ground [12]. Fig.1 shows schematic arragement of solar street lighting system.

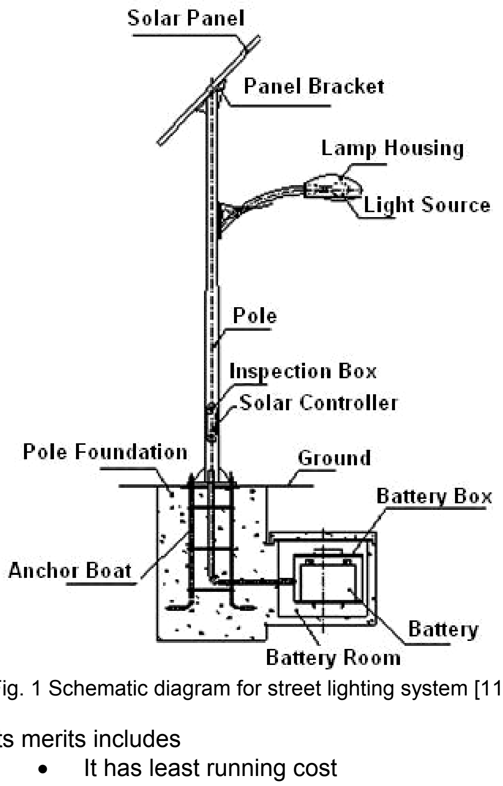

Fig. 1 Schematic diagram for street lighting system [11]

Its merits includes

- It has least running cost
- It is free from pollution and is a green source of lighting
- No external connections are needed, the risk of accidents is very much minimum
- It can be accessed and monitored remotely
- Its maintenance charges are very much low

Its demerits includes

- Its capital cost is very much high
- The chance of theft is at easy end
- The batteries requires replacement after their deep discharge
- Its working is ambiguous during cloudy and rainy seasons
- Its performance gets affected by moisture and snow

Research Methodology
The main benefits of city street lighting system include the provision of security to communities and improvement of driving visibility contributing to safer movement on the road and in the streets as shown in Fig. 2.


Fig. 2 Luminance of solar powered LED lights during the night hours with two lanes

The capital cost of SLS (Installations, maintenance and operation cost), however, is a huge burden on all city governments in Pakistan. Since the cost of project includes projection charges, construction charges and getting the accessories to function fully by hiring skilled personals [13]. This research is based on technical and economical feasibility of LED based SLS in Pakistan. Since the major cost accompanied with high pressure sodium and mercury lights is actually based on their maintenance and operation [14]. The average life span of street lamps is 7 years if there are no frequent variations in voltages [14]. The operational and maintenance cost for street lighting system is 1-2% of the total cost of project per year [15]. The operational and maintenance cost includes clearing the solar panels and light lamps and expenditure on inspection of associated auxiliaries [15]. Since in Pakistan, there are four seasonal changes, but the project needs maintenance during winter season as the load demand is least. The cost of operation and maintenance can be accounted by equation (1) [15]

(1) $$C_{MO} = 0.02 \times C_C$$

where C_{MO} is the maintenance and operation cost and C_C is the capital cost.

Along with the cost of operation and maintenance, there is another cost related with the replacement of faulty and wear equipments like, batteries and LEDs mostly. The battery used in such applications is the lithium battery, whose life span is expected to be the twice of an ordinary battery. The normal life span of lithium battery is 5 years [15], therefore for the projection of 20 years, on estimate 4 battery will be replaced roughly.

The projection years for suggested solar powered LED based SLS scheme is 20 year, based on the life expectancy of solar panels by distributers which is also 20 years [16]. The street lights on usual basis remain on for 12 hours a day. The life span of LED lights is 55,500 hours which means it will be replaced after every 11 years if and only if the environmental and physical conditions remain same. The comparative analysis between LED and Sodium vapor lamps is shown in Table. 01[16].

Table. 01 Performance discrimination between Sodium vapor lamp and LED

Sr. No.	System Parameter	Sodium Vapor Lamp	LED
1	Lamp Wattage	250 W	100 W
2	System Wattage	280 W	100 W
3	Luminous Efficacy	110 lm/W	130 lm/W
4	System Efficacy	90 lm/W	130 lm/W
5	Coverage	0.84 W/m^2	0.36 W/m^2
6	Life span	12k hours	50k hours
7	Color Rendering Index	<65	>75
8	Hazardous Material	Yes	No

To know the details of the cost of replacing the batteries and lights, equation (2) [17] can be used

$$C_R = \frac{C_U \times T_S \times n}{T_P} \quad (2)$$

where C_R is the cost of replacement, C_U is per unit cost, T_S is the service period, n is the number of units used and T_P is the projected life span.

Next we have to account for electricity consumption, since normally the street lights work from 6 P.M to 6 A.M. During this work period the cost of electricity is always billed at higher rates. Therefore cost of energy consumption can be accounted by equation (3) [17]

$$C_E = P_L \times n \times T_R \times B_C \times T_T \quad (3)$$

Where C_E is the cost of energy consumption, T_R is the running time period, B_C is the capacity of battery, T_T is the total time span and P_L is load power.

Now calculating Net Present Value (NPV) and Benefit Cost (B/C) ratio as to whether or not the investment is quite feasible to be implemented, by using equation (4) and (6) respectively [15], where E_U is the cost of single energy unit, C_T is the total accumulative cost per year, I is the internal rate of return and K is the year of accountability.

For the n projection year, the total cumulative NPV can be accounted by equation (5) [15]

$$(NPV)_K = \frac{C_E \times E_U \times C_T}{(1`+I)^K} \quad (4)$$

$$(NPV)_C = (\sum P_R - \sum P_E) \quad (5)$$

$$B/C = \frac{\sum R_T}{\sum C_E} \quad (6)$$

where, P_R is the revenue price, R_T is the total revenue on project implementation and C_E is the total expenditure, P_E is energy price.

Results & Discussion

A. Conventional Street Lighting System

Since in the conventional street lighting, the major cost involved, is on the electricity consumption by the sodium vapor street lights. It has been calculated on average the conventional SLS based on 500 sodium vapor lights consumes 547,500 kWh/year. In conventional we do also need transformers, which is also one of the costly power equipment. The total cost for implementing conventional SLS in the urban region of Pakistan is shown in Table. 02.

Table.02 Cost evaluation of traditional SLS

Component Description	Quantity	Cost per unit (PKR)	Cumulative Cost (PKR)
Sodium vapor light (250 W)	500	2800	1,400,000
Electric Pole	250	3500	875,000
Transformer	2	450000	900000
Cable	6	45×4.25×100	114,750
Labor Cost	500	1200	600,000
Deployment Cost	500	1500	750,000
Miscellaneous	500	1700	850,000
Electricity cost	12 hr ×500×250	15/kwh	8,212,500
Total Capital Cost			13,702,250

The main cost of high pressure sodium lighting is lamp replacement and gas refilling. It includes equipment purchasing fees and worker's wages. The average lifespan of street lamps is five year if no voltage fluctuation affects the lamps. Considering light refilling, replacing, labor cost and other maintenance cost, we consider a total maintenance and operation cost of PKR (0.02 ×13,703,250 = 274,065).

B. LED based Street Lighting System powered through utility network

By replacing sodium vapor lamps with LED, the efficiency of system would improve but eventually the over cost of installation would be higher as shown in Table. 03. Since the LEDs have low power consumption as compared to sodium vapor lamps. The electricity consumption for such proposition is 219, 000 kWh/yr. The extra investment in such project comes from its AC/DC converter cost, expensive erecting poles, and costly labor and deployment costs.

Table. 03 Cost evaluation of grid-powered LED based SLS

Component Description	Quantity	Cost per unit (PKR)	Cumulative Cost (PKR)
LED (100 W)	500	7500	3,750,000
Pole	250	6500	1,625,000
Transformer	2	450000	900000
Cable	6	45×4.25×100	114,750
AC/DC Converter	250	2650	662,500
Labor Cost	500	2500	1,250,000
Deployment Cost	500	2300	1,150,000
Electricity Cost	12hr×500×100	15/kWh	3,285,000
Miscellaneous	500	2500	1,250,000
Total Capital Cost			13,987,250

The life span of LEDs is much higher than that of sodium vapor lamps, so there will be no frequent replacement. But due to the sensitivity of project, the deployment should be done through skilled personnel. Therefore, the overall maintenance and operation cost for such kind of project would be PKR (0.02×13,987,250 = 279,745). The M & O cost saved on replacement has been compensated by skilled worker wages.

C. Solar Powered LED based Streeting Lighting System

Since the cost of electricity consumption after implementing solar power system for SLS is compensated by the replacement of battery within the life span of 5 years but still a large amount of money will be saved i.e. (547,500 x 15) – (14000 × 4 × 250) = PKR 5,787,500 . Table. 04 contains the cost evaluation of solar powered LED based SLS project.

Table. 04 Cost evaluation of solar powere LED based SLS

Component Description	Quantity	Cost per unit (PKR)	Cumulative Cost (PKR)
LED (100 W)	500	7500	3,750,000
Solar Module (220 W_p)	250	19800	4,950,000
Battery (200Ah, 12V)	250	14000	3,500,000
Charge Controller	250	8400	2,100,000
Pole	250	11700	2,925,000
Lamp Bracket	250	2200	550,000
Battery Box	250	700(8212500	175,000
Labor Cost	500	1800	900,000
Deployment Cost	500	2300	1,150,000
Miscellaneous	500	2500	1,250,000
Total Capital Cost			21,250,000

Economic viability of solar powered Street Lighting System

The economic viability of the solar powered LED street lights will be determined by establishing the Simple Payback Period for the life span of the project

•Annual Energy Savings = 500 street lights × 4,350 hours per year × 75W per luminaire savings ×15 kWh rate = PKR 2,446,875.

Annual Maintenance Savings = 500 street lights × PKR 3000 per fixture per year savings (the solar module has useful life of 20 years. The LED lights used in SLS projects have life expectancy of 55, 500 hours, which approximately calls for 11 years without any replacement; the charge controller and pole have life span of 11 years and 30 years respectively) = PKR 1,500,000, which indirectly accounts for labor and plus the associated material.

Total Annual Savings = PKR 2,446,875 + PKR 1,500,000 = PKR 3,946,875

Simple Payback = 21,250,000/3,946,875 = 5.384 years.

Table.05 Pay back analysis of solar powered SLS project for 20 years

Year of Projection	Capital Investment [PKR]	Net Encashment Flow [PKR]	Cumulative Encashment [PKR]
Initial	21,250,000	-21,250,000	
1st		3,946,875	-17,303,125
2nd		3,946,875	-13,356,250
3rd		3,946,875	-9,409,375
4th		3,946,875	-5,462,500
5th		3,946,875	-1,515,625
6th		3,946,875	2,431,250
7th		3,946,875	6,378,125
8th		3,946,875	10,325,000
9th		3,946,875	14,271,875
10th		3,946,875	18,218,750
11th		3,946,875	22,165,625
12th		3,946,875	26,112,500
13th		3,946,875	30,059,375
14th		3,946,875	34,006,250
15th		3,946,875	37,953,125
16th		3,946,875	41,900,000
17th		3,946,875	45,846,875
18th		3,946,875	49,793,750
19th		3,946,875	53,740,625
20th		3,946,875	57,687,500

While working the value of equipments depreciated as they are degraded with passing time span. In order to account the depreciation charge on deployed SLS project, sinking fund method is used. The sinking fund method accounts for constant depreciation charge every year and take on the interest at compound rates [18]. The fixed depreciation charge is calculated in such a way that it accumulates the total cost on installation plus the interest on it annually, that must be equal to the cost of replacement after the useful life of project after payback time. Sinking fund can be found by equation (7) [18]

(7) $$S_F = (M - N)[\frac{k}{(1+k)^n - 1}]$$

where S_F –Sinking Fund, M-Initial value of equipment, N-Scrap value after useful life, n-useful life of equipment in years, k- Annual rate of interest expressed as decimal

With an interest of 5%, the annual deposit under sinking fund method is

(8) $$3{,}946{,}875 = (21{,}250{,}000 - N)[\frac{0.05}{(1+0.05)^{5.384} - 1}]$$

From it, the scrap value would be;
N= PKR -2,431,250

This amount of money would be saved after the useful time of solar powered LED based street lighting system. It can also be confirmed from the table. 05, that at the end of 6th year, the amount saved is PKR 2,431,250 too. This confirms the viability of this research work.

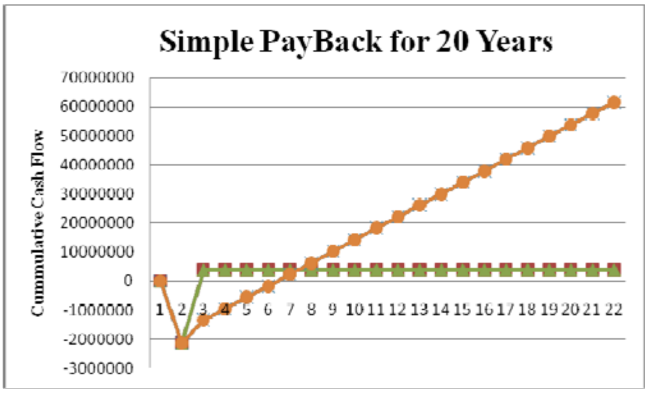

Figure.02 Graphical analysis of revenue encasement for 20 years

Figure.02 shows the cost return and revenue production for deployed solar powered SLS project. It can be visualized from table 5 and figure. 02 that the revenue on project starts at 6th year and it goes on increasing till the projected end of year. Since the payback is straight due to insurance coverage on all the associated equipments by the supplier and manufacturer for 20 years. In the mean while, during maintenance and repair, the company also provides additional modules to assure availability and service of deployed solar powered SLS network.

Energy Savings

This section describes the amount of energy consumed if the conventional lights are to be replaced by LED lights.

For a total of 500 sodium vapor lamps fitted with a capacity of 250 Watts in use from 6pm – 6am (12 hours) [19].
The energy consumed by the conventional SLS is given below;

Energy utilized per year = No. of units consumed × power rating × net kWh =

= 500 x 250x 12 x 365=547,500 kWh/yr

The energy consumed by grid powered LED based SLS is

Energy utilized per year = No. of units consumed × power rating × net kWh =

= 500 x 100x 12 x 365=219,000 kWh/yr

% Energy Saving = (547,500-219,000)/547,500 = 60%

This amount of energy will be saved if all the sodium vapor street lights are replaced with LED streetlights.

HOMER Analysis

The HOMER software was used to determine the economics of the SLS. With the help of input parameter, the hybrid [solar+grid supply] steet lighting system was implemented in HOMER software for its economic analysis. The renewable energy input along with storage in Lithium ion battery was used. A DC/AC and AC/DC converters were used for load compatibility. In HOMER analysis, the initial step is to determine the average hourly load profile of the system for each month. The bar plot in Fig.4 determines the hourly load profile and the bar plot in the Fig.5 gives the average monthly load profile.

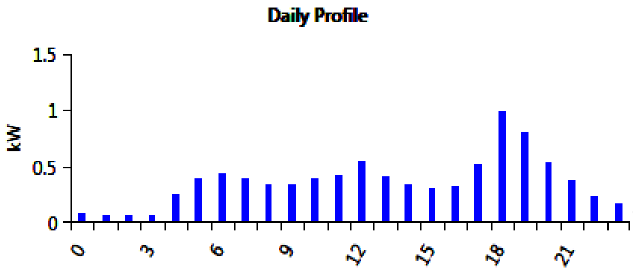

Fig.4 Daily load profile

The second step is to dedicate suitable amount of renewable energy source devices and other components utalized in the hybrid street lighting system. The Table 1 illustrates the components used in the system and their particular size, quantity, Life time and miscellaneous costs. The schematic diagram of the system in HOMER software is shown in the Fig. 6.

Table 6. HOMER software input data

Component	Model or Size	Lifetime (Years)	Purchase Cost ($)	Replacement Cost ($)	Maintenance Cost ($)
PV Array	1 kW	25	1000	1000	10
Battery Bank	12 V, 1 kWh	10 Years	100	100	10
Power Converter	1 kW	15	100	100	0

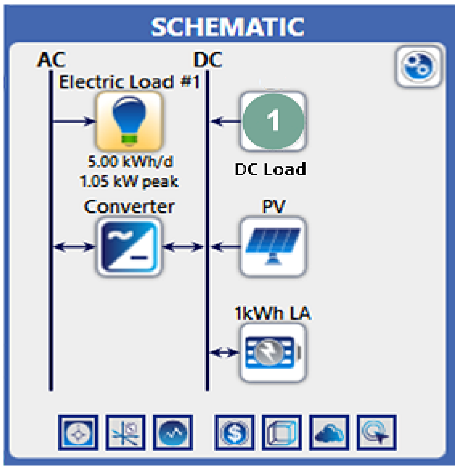

Fig. 6 HOMER analysis of Hybrid SLS

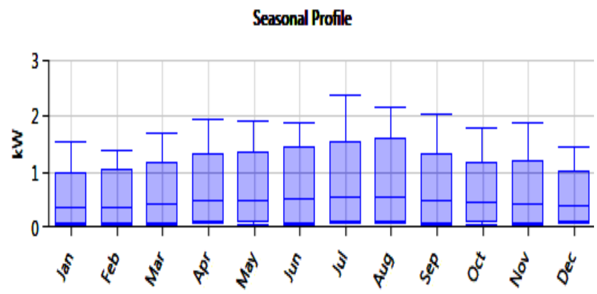

Fig.5 Seasonal load profile

Conclusion

The street lighting system is the key feature in the development of any country. In this research work, the economical analysis of deployed traditional street lighting system (SLS) and suggested solar powered LED based project were carried. The capital cost on SLS for different scenario was calculated in Tables. 1, 2, 3, & 4. It was found that if only the sodium vapor lamps are replaced with LEDs and the system is again powered by utility network, then annually 219,000 units of energy can be saved with a cost margin of PKR 279,745. But if solar powered LED based SLS project completely replaces the traditional SLS then annually 547.500 units of energy can be saved with a cost margin of 274, 065. Since the initial cost of suggested project is very high but it was calculated that payback time for this project is 5.384 year and after that the actual revenue out flows to investor. The scrape value of system after its useful, as calculated was PKR -2,431,250, which was accumulated at the end of 6th year by means of simple payback.

Finally it can be concluded that with the replacement of traditional SLS with solar powered LED based SLS project, not only the efficiency of system increases but it also accumulates for reducing load shedding thereby saving 547, 500 units of energy annually, which can be then supplied to the local consumers. The annual energy saving of the suggested project, as per calculations is 60% even if only sodium vapor lamps were being replaced by LED lights. The same results were obtained when analyzed through HOMER software, with proper purchase cost, replacement cost, and maintenance cost and life time.

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REFERENCES

[1] http://icci.com.pk/data/downloads/63/1293619048_1.pdf

[2] Hafiz Bilal Khalil "Energy Crisis and potential of solar energy in Pakistan" Renewable and Sustainable Energy Reviews 31 · Vol 91(4) December 2013

[3] http://www.cpec.gov.pk/brain/public/uploads/documents/China-Pakistan-Economic-Corridor-English-Booklet.pdf

[4] N. R Velaga , A. Kumar, "Techno-economic Evaluation of the Feasibility of a Smart Street Light System: A case study of Rural India",2012, Social and Behavioral Sciences, Vol.62, pp. 1220 – 1224

[5] A. Athanasia, L. Papatsoris, D. Anastassios "The Economic of Photovoltaic Stand-Alone Residential Households :A Case Study for Various European and Mediterranean Location". Heslingtong : Department of Electronics University of York, 2000

[6] B. J. Huang, M. S Wu, H. H. Huang "Economic Analysis of Solar-Powered Led Roadway Lighting" Proceedings of ISES World Congress 2007 (Vol. I – Vol. V) pp 466-470

[7] L. Al-Kurdi , R. Al-Masri A. Al-Salaymeh "Economical Investigation of the Feasibility of Utilizing the PV Solar Lighting for Jordanian Streets" Int. J. of Thermal & Environmental Engineering Volume 10, No. 1 pp. 79-85 (2015)

[8] J. Tsado, M.A Ganiyu , "Engineering economics of solar based street lighting in Nigeria", Journal of economics and engineering, 3(1), 13-16 (2012).

[9] B. Xuemei , "RIZHAO, CHINA: Solar-Powered City", World Watch, (2007) Vol. 20(2), pp. 31-60

[10] K.A Kumar, K. Sundereswaran, P.R Venkateswaram, S. Palani, B.R Naina "Design, implementation and economic analysis of sustainable LED roadway lighting system in industrial environment" (2015) International Conference on Industrial Instrumentation and Control (ICIC), IEEE explorer

[11] http://www.solar-street-light.com/content/23-solar-street-lights-construction

[12] S. d Ingegneria "The solar LED street light" Master of Science Degree in Electrical Engineering Degree Thesis, Department of Information Technology, UNIVERSITY OF PADUA July 2013

[13] P. Fabrício. V. Lucila, M.S. Campos, N.C Filho, "Sustainability constraints in techno-economi analysis of general lighting retrofits" Journal Energy and Building, Vol. 5 (2), pp.500-507 (2012)

[14] C. K Gan, A. F Sapar, Y. C Mun, K. E Chong, " Techno-economic Analysis of LED Lighthing: A case Study in UTeM's Faculty Building", in Malaysian Technical Universities Conference on Engineering & Technology (2012), MUCET 2012, pp.208-216

[15] I.S Mardikaningsih, W. Sutopo, M. Hisjam, R. Zakaria " Techno-economic Feasibility Analysis of a Public Street Light with Solar Cell Power" Proceedings of the International MultiConference of Engineers and Computer Scientists 2016 Vol II, IMECS 2016, March 16 - 18, 2016, Hong Kong

[16] IEEE Std.2362TM-2003. IEEE Guide for selection, charging, test, and evaluation of lead-acid batteries used in stand-alone photovoltaic (PV) system

[17] B.J Huang, M.S Wu, C.J Wu. Development and field test of a long-lasting solar LED lighting system, Word Renewable Energy Congress IX August 19-25, 2006 p. 590.

[18] H. S. Al. Mohammed "Large Scale Desalination: A Comparative Cost Affective Economic Analyses of Nuclear, Gas and Solar Powered Plants", Theoretical Economics Letters, 2015.

[19] American National Standard Practice for Roadway Lighting. Illumination Engineering Society of North America Report #RP-8-00, August 1999.