LED Lighting as Energy Management Tool through Correlation Analysis of Daily Electricity Demand and Supply Curve

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***Abstract*— Power industry has restructured in last decades and now it has become a commodity rather than a utility with the maximization of profit as its main purpose. Peak ripples in the electricity demand curve could disturb the economic generation. In developing countries, Electric Supply Companies are unable to meet the existing power demand due to unfeasible and unjustified fuel burning. Therefore, they are left with load shedding as the only Demand side solution. It is a well-known fact that the Light Emitting Diodes (LED) Lighting could be used to conserve electricity. However, LED could also be used as an energy management technique without affecting the comfort level of consumer. Electricity demand and supply curves could be correlated up to 93% through this option. Argument is supported by correlation analysis of estimated daily demand and supply curves of Karachi Electric Supply Company (KESC). Estimated curves are developed through LED lighting energy conservation analysis on KESC summer and winter demand curves. Finally, from global perspective, LED lighting is not only a remedy for removal of peaks and ripples in demand curve but also a feasible solution for global climate problems through energy conservation and low carbon emissions.**

Keywords- Daily load curves, Energy conservation, LED.

I. INTRODUCTION

For any developing country like Pakistan, the economic stability is of grave significance. The economy of the country is vastly affected by the electrical power shortage [1]. The utility companies have failed to meet the increasing power demands of the consumers within strategic profit maximization due to variations in daily curve and dependency on oil and gas [2].The increasing hours of load shedding have caused a wave of frustration in the general public leading to protests, strikes and political instability. Furthermore, self-generation in commercial and industrial sectors is not only increasing the inflation rate but also adding to the contamination of the environment.

According to recent reports, several companies have shifted their business from Pakistan due to electric power shortage and worsening conditions of law and order [3]. This is a major blow to the collapsing economy of the country and if serious measures are not taken to resolve the power crisis of Pakistan, the country will find itself at an alarming stage. Electricity generation is responsible for 41% Green House Gases (GHGs) in total global GHGs [4].The increase in generation would not only require local and foreign investments but would also have harmful effects on the environment due to addition in GHGs. Moreover, the transmission system in the country is already working on its full capacity [5] and the construction of new transmission lines would require more investment which is not possible in the current scenario. Distributed generation, like solar and wind energy systems, is required due to the limitations in transmission capacities [6]. Off-grid solar and wind energy systems are currently very expensive due to the periodic cost of batteries which makes them unfeasible [7]. On the other hand, dynamic power system is required to avoid the use of batteries and to move towards On-grid power solution [8].

Energy efficiency is a reliable, sustainable and economical way to overcome the power deficit as part of both short term and long term power system planning [9]. Power demand can be permanently reduced with the help of smart appliances [10]. There is a need for government to motivate the manufacturers for making smart, energy efficient appliances in order to permanently reduce the demand without causing any further damage to the environment. As compared to various proposed demand side management techniques [11], it does not require any management or controlling system to optimize the power demand by shifting of peaks.

KESC is mainly dependent on fossil thermal power plants which are suitable for base load [12]. It is critically important to shift peaks and valleys of demand curve to handle problems of intermediate and peak loads. Although generation capacities are available to meet the demand but it is not a feasible option to utilize thermal power plants for peak loads.

In this paper, it is proposed that power demand and supply be optimized by optimizing daily load curves. Major load contributors can be analyzed to optimize the daily demand curve. It was observed that lighting and air conditioning load contribute significantly to the total demand. Therefore, energy saving from lighting load and air conditioning load (ACL) could adequately reduce energy consumption. Lighting load contributes 20% to 40% of the total demand of the country [13]. Scope of this paper is limited to lighting load but similar research can be carried out for ACL.

Many policies were made to move towards efficient lighting options [14]. In Pakistan too, energy efficiency program was started by the government in which 30 million compact florescent lamps (CFLs) were planned to be distributed free of cost. Through this program, $1.84Billion were estimated to be saved by avoiding generation of 1600MW [15]. Significant energy is conserved by the use of CFL but the power factor of these lamps is 0.57. This consequently increases the reactive power demand of the system along with increase in the harmonic level and voltage distortion of the system [16].

The use of LED lamps is a recommended option not only due to its better performance as compared to other technologies but also due to its ability to significantly manipulate the demand as proposed in this paper. The LED lamp has a long life as compared to other lighting schemes so the replacement cost of frequently changing the lamps will also be reduced [17]. Moreover, the LED lamps can be installed in existing lighting fixtures without the need of renovation in existing buildings as compared to other energy conservation techniques like in phase change material to store heat in a room [18-20].

Karachi city has been taken as a pilot project, and the data of KESC has been used to carry out this research, but this research is equivalently applicable in other countries due to the same kind of loads and global objectives to save this world from climate change and associated problems. In this paper, Section II explains the existing electricity scenario to understand the scale of problem. Extensive lighting load data is summarized in Section III which is used to estimate energy savings in section IV through plotting expected demand curve using LED lamps. In section V the effects of LED lighting are analyzed on daily load curves of summer and winter, while in section VI results are quantified by co-relating the supply and demand curves. Finally, the results are discussed in section VII followed by conclusion.

II. EXISTING POWER DEMAND AND SUPPLY

Existing power industry scenarios and demand patterns are very important to start with the impacts of LED lighting scheme on the total power demand and daily load curves. For this purpose, Karachi has been taken as a pilot research zone.

Pakistan is a developing country and Karachi is a major contributor in its economic growth. Domestic, commercial and industrial sectors are the major electricity demand contributors in Karachi as shown in Figure 1 [21]. Thus, for reducing the power demand of the city, these sectors should be the main area of focus. When aiming to reduce the power demand of a particular sector, it is critically important to monitor the daily load curves of that sector. The pattern of the daily load curve remains more or less the same throughout the year but differs only due to seasons and environmental temperature. From distribution point of view, the seasons of summer and winter are very important as the consumer demand in these seasons is very different. To analyze the supply and demand curves of summer and winter the curves of KESC are taken as a model.

It is worthwhile to note that the power shortage on a hot day of summer was increased up to 500MW i.e. 20% of total demand as shown in Figure 2. Similarly, in winter, the demand was increased to some 1900MW while the utility company was only successful in generating 1500MW with economic feasibility which resulted in excessive load shedding of up to 400MW as can be observed in Figure 3.

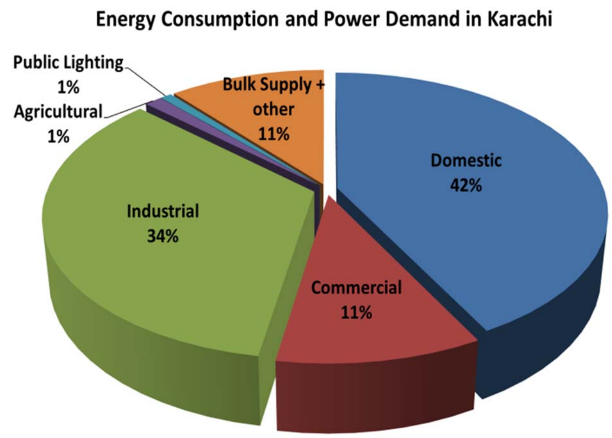

Fig. 1. Sector wise Energy Consumption of Karachi (Year 2010-11)

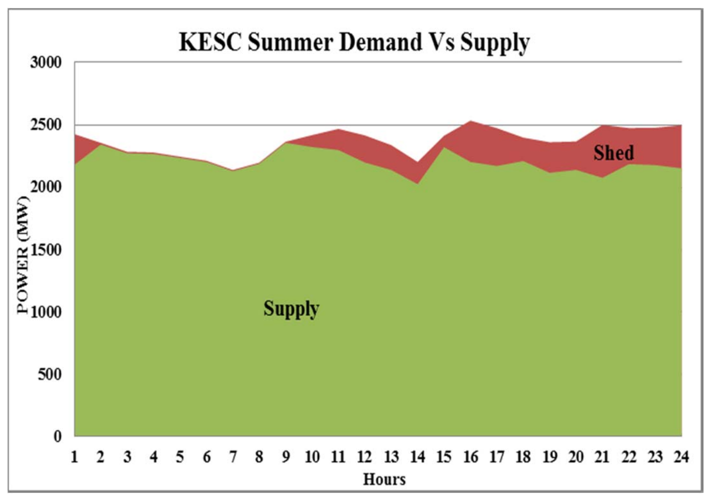

Fig. 2. Summer Day Demand Curve of Karachi (14th July 2010)

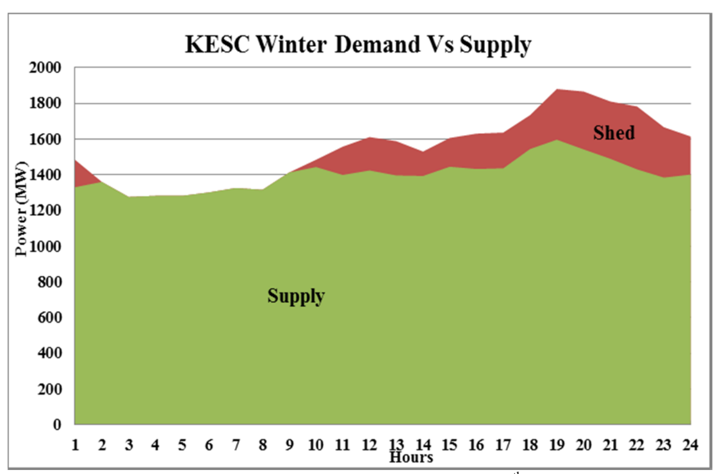

Fig. 3. Winter Day Demand Curve of Karachi(9th Nov 2010)

III. LIGHTING LOAD RESEARCH

To study the effects of LED lighting on total demand curves, it is first necessary to know the lighting load curves of KESC. Detailed research on lighting load was conducted to estimate lighting load share in daily load curves of Karachi. Lighting load data have been collected through energy audits, surveys, lighting projects, building design projects of M/S Natural Reflection Energy Solution (Lighting designer and lamps provider), M/S SA Engineering (Electrical contractor) and M/S ARCS MEN (Consultant). This data was only sufficient for verifying industrial and commercial lighting loads. A survey was taken through 800 students of electrical engineering department of NED University to verify residential loads.

Lighting load research shows that the domestic, commercial and industrial sector have collective share of 86% in total lighting load of Karachi as shown in Figure 4. The lighting load contributes to 18.10% of the total electricity demand of Karachi which adds up to 453 MW as summarized in Table I. This percentage is almost similar to the lighting load of United Kingdom and other countries [22].

In summer, the lighting load can cause a peak of as much as 500 MW while in winter peaks of 550 MW occur on daily basis due to longer nights as shown in Figure 5. Thus, if the lighting load is somehow reduced, it will adequately modify the electricity demand curve.

TABLE I SECTOR WISE POWER DEMAND AND LIGHTING LOAD (2010-2011)

Sector	Power Demand(MW)	Annual GWh	Lighting load %	Lighting load in MW
Domestic	1,057	4257	20%	211.33
Commercial	259	1043	40%	103.55
Industrial	856	3447	8.3%	71.27
Agricultural	31	125	14%	4.34
Public Lighting	20	82	100%	20.35
Bulk Supply + other	278	1118	15%	41.63
Total	2500	10,072	18.10%	453

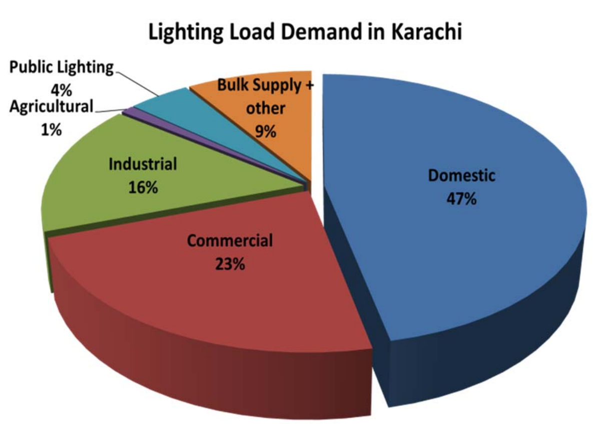

Fig. 4. Lighting load Distribution of Karachi (Year 2010-2011)

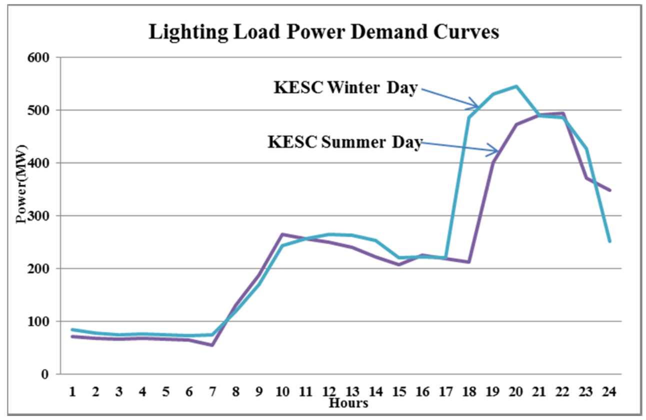

Fig. 5. Daily Lighting Load Demand Pattern (Year 2010-2011)

IV. ELECTRICITY SAVING ANALYSIS THROUGH LED LIGHTING

Different lighting technologies are being used presently in different sectors, so it is important to study all of them separately. It is also vital to calculate the individual energy conservation factor of each technology for observing the difference with LED, which is shown in Table II. If all the lighting schemes in each sector are replaced by LED, then 62% of lighting load could be reduced i.e. about 284.6MW as summarized in Table 2. However only 60% have been considered for the purpose of calculations. With this reduction of the lighting load, the projected lighting peak in summer would be of 300MW which previously was of about 500MW. Similarly, in winter, the peak will be abridged to 320MW from 550MW as plotted in Figure 6.

TABLE 2: SECTOR WISE DEMAND REDUCTION OF LIGHTING LOAD (YEAR 2010-2011)

Lamp type	Domestic	Commercial	Industrial	Agricultural	Public Lighting	Bulk Supply	Total(MW)	% LED Savings	Saving(MW)
CFL	61.5	39.4	11.4	1.5	0.0	11.2	125.0	0.5	56.3
EBFL	21.2	4.1	7.8	0.2	0.0	3.1	36.5	0.5	18.3
MBFL	74.2	31.1	32.1	1.1	0.7	15.4	161.5	0.7	113
IL	33.9	20.7	0.7	0.9	0.0	4.2	60.4	0.9	52.5
MH	12.7	7.3	14.3	0.2	2.0	5.8	42.3	0.7	29.6
LED	2.1	1.0	1.4	0.0	0.0	0.8	5.4	0.0	0.0
Others	6.4	1.0	3.6	0.4	17.6	0.8	29.8	0.5	14.9
Total	212	105	71.3	4.3	20.4	41.4	461.0	0.62	285

where,

CFL stands for Compact florescent lamp,

EBFL stands for Electronic blast florescent lamp,

MBFL stands for magnetic blast florescent lamp,

IL stands for Incandescent lamps

MH is the abbreviation for Metal halide while others include other gas discharge lamps such as high and low pressure sodium lamps etc.

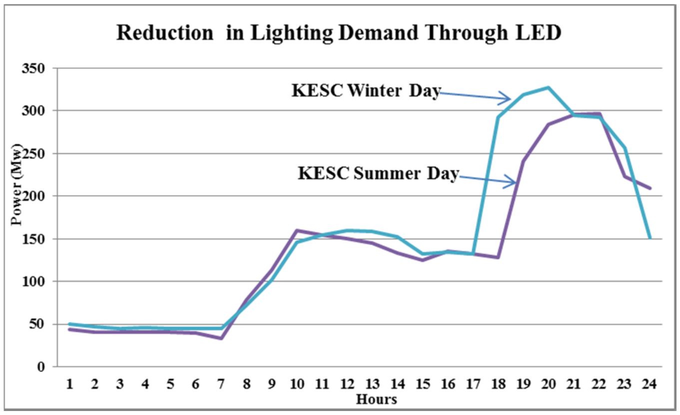

Fig. 6. Daily Electricity Demand Reduction through LED

V. Analysis of LED Lighting on KESC Load Curve

The presented scheme could help in manipulating the daily curve as per existing power shortage. It would not only reduce the demand but would also yield huge financial profits to the KESC due to removal of peaks.

The power shortage and power saving through LED curves are compared, to estimate the expected demand curve. Correlation analysis is carried out to estimate the similarity factor of the available electricity supply curve to the existing and expected demand curves of summer and winter daily load curves.

A. Daily Load Curve In Peak Summer

Previously, in summer, the wide gaps between demand and supply caused excessive load shedding. When LED is used the power saving curve of LED moves simultaneously with the shortage curve as shown in Figure 7. This means that as the shortage increases, the saving increases too, denoting that the lighting load contributes significantly to shortage peaks. Electricity deficit could be reduced from 500MW to 150MW. It means that 70% of total electricity deficit in peak summer can be reduced through LED lighting as can be observed in Figure 8. It would not only help in reducing peaks and ripples but it is also a feasible method for KESC to maximize its revenue.

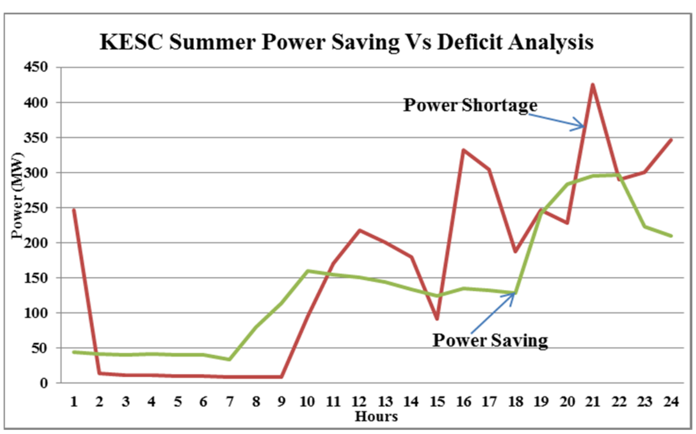

Fig. 7. Summer Day Power Deficit and Expected Demand Reduction

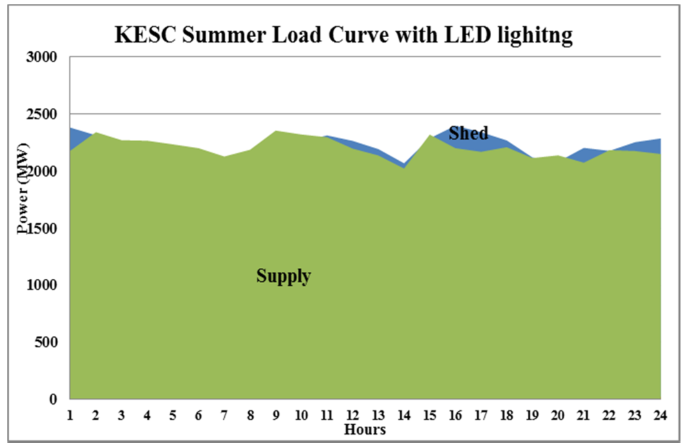

Fig. 8. Expected Summer Day Demand and Supply Curve

B. Daily Load Curve In Peak Winter

Similarly, in winter, a large amount of energy can be saved through LED lighting as the power saving curve follows the power deficit curve as can be observed in Figure 9. The power shortage has reduced from 350MW to 40MW and at some point the gap between demand and supply has completely diminished as can be seen in Figure 10.

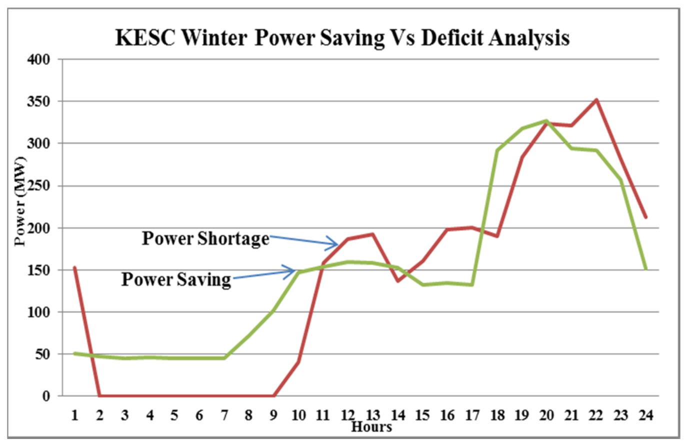

Fig. 9. Winter Day Power Deficit and Expected Demand Reduction

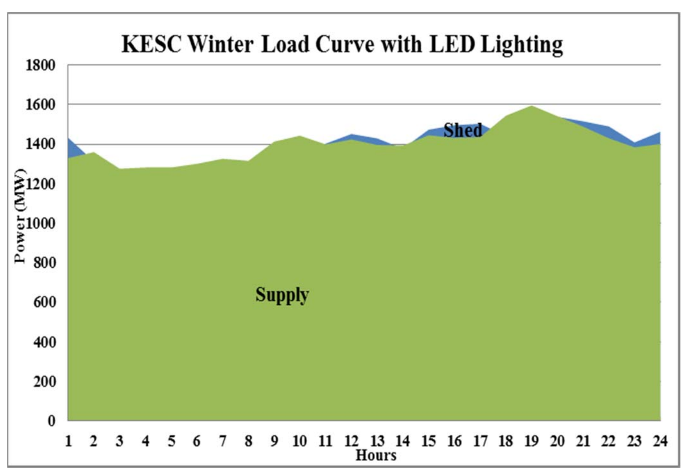

Fig. 10. Expected Winter Day Demand and Supply Curve

VI. CORRELATION ANALYSIS

Correlation analysis is an effective statistical tool to determine the similarity factor between two variables. In this section, this tool has been to determine the similarity between electricity demand and supply curves. The existing and expected demand (MW) and supply (MW) in summer and winter season after considering the impact of LED lamps is shown in Table 3 and Table 4 respectively.

TABLE 3. SUMMARY OF POWER DEMAND AND SUPPLY IN SUMMER

Hours	Demand (A)	Supply (B)	KESC Lighting load	KESC Power Saving	Expected Demand (C)	Expected Supply (D)
1	2425	2178	72.6	43.56	2381.44	2178
2	2355	2341	68.3	40.98	2314.02	2314.02
3	2283	2271	66.9	40.14	2242.86	2242.86
4	2277	2266	68.31	40.98	2236.01	2236.01
5	2244	2234	67.32	40.39	2203.60	2203.61
6	2211	2201	66.33	39.79	2171.20	2171.2
7	2137	2128	55.562	33.33	2103.66	2103.66
8	2196	2187	131.76	79.05	2116.94	2116.94
9	2364	2355	189.12	113.4	2250.52	2250.53
10	2417	2321	265.87	159.5	2257.47	2257.48
11	2467	2297	256.57	153.9	2313.05	2297
12	2415	2197	251.16	150.7	2264.30	2197
13	2337	2137	240.71	144.4	2192.57	2137
14	2202	2023	222.4	133.4	2068.56	2023
15	2412	2320	207.6	124.5	2287.44	2287.44
16	2533	2201	225.44	135.2	2397.73	2201
17	2473	2169	220.1	132.0	2340.94	2169
18	2397	2209	213.33	128	2269.00	2209
19	2360	2114	401.2	240.7	2119.28	2114
20	2366	2138	473.2	283.9	2082.08	2082.08
21	2499	2074	492.3	295.3	2203.62	2074
22	2474	2184	494.8	296.8	2177.12	2177.12
23	2476	2176	371.4	222.8	2253.16	2176
24	2496	2150	349.44	209.6	2286.33	2150

TABLE 4. SUMMARY OF POWER DEMAND AND SUPPLY IN WINTER

Hours	Demand (E)	Supply (F)	KESC lighting load	KESC MW Saving	Expected Demand (G)	Expected Supply (H)
1	1483	1330	84.38	50.63	1432.372	1330
2	1360	1360	78.74	47.24	1312.756	1312.76
3	1276	1276	75.03	45.02	1230.982	1230.98
4	1282	1282	77.17	46.3	1235.698	1235.7
5	1282	1282	74.74	44.84	1237.156	1237.16
6	1301	1301	74.5	44.7	1256.3	1256.3
7	1326	1326	75.31	45.19	1280.814	1280.81
8	1316	1316	120.28	72.17	1243.832	1243.83
9	1413	1413	170	102	1311	1311
10	1484	1443	244.12	146.5	1337.528	1337.53
11	1557	1399	256.9	154.1	1402.86	1399
12	1611	1424	265.82	159.5	1451.508	1424
13	1588	1396	264.40	158.6	1429.359	1396
14	1530	1393	253.98	152.4	1377.612	1377.61
15	1606	1445	221.15	132.7	1473.31	1445
16	1630	1432	223.31	134	1496.014	1432
17	1636	1436	221.35	132.8	1503.19	1436
18	1734	1544	487.6	292.6	1441.44	1441.44
19	1880	1596	530.72	318.4	1561.568	1561.57
20	1866	1542	546.18	327.7	1538.292	1538.29
21	1810	1489	490.51	294.3	1515.694	1489
22	1782	1430	487.02	292.2	1489.788	1430
23	1666	1384	428.33	257	1409.002	1384
24	1614	1401	252.59	151.6	1462.446	1401

In general, the coefficient of correlation (r) can be calculated by using equation (1).

$$r = Correl(X,Y) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \qquad (1)$$

where $\bar{x}$ and $\bar{y}$ are the sample means of both variables.

The coefficient of determination (CoD) in terms of percentage can be used to determine the similarity factor between two variables. CoD can be calculated by using equation 2.

$$\text{CoD} = r^2 \qquad (2)$$

Coefficient of correlation (r) along with coefficient of determination (r^2) have been calculated for summer and winter in both scenarios i.e. before and after replacing LED lamps with traditional lighting schemes as summarized in Table 5.

TABLE 5. SUMMARY OF CORRELATION ANALYSIS

Weather	Point	Variables: Demand	Variables: Supply	r	r^2	Similarity %
Summer	Before	A	B	0.0999	0.01	1.00%
	After	C	D	0.6667	0.4445	44.45%
Winter	Before	E	F	0.9002	0.8104	81.04%
	After	G	H	0.9287	0.9287	92.87%

VII. RESULTS AND DISCUSSIONS

As Summarized in Table 5, it was found that the existing demand and supply curves were only 1% similar during summer season. When the correlation technique was applied to the predicted curves after the reduction of demand with LED lighting, the similarity factor was improved to 44.45%. Similarly, in winter season the existing curves of demand and supply were 81% similar while this similarity factor increased to 92.87% with the use of LED.

With this drastic improvement in the similarity of curves and conservation of energy, the utility company overcome the power demand with economic feasibility without having the need of investing money in power generation and transmission.

VIII. CONCLUSION

Energy conservation from LED lighting is a well-known fact. In this paper the use of LED lighting scheme is proposed as a demand side management technique to modify the peaks and ripples in the electricity demand curves as per available supply. With the quantification of the impacts of LEDs, it was observed that the demand curves could be modified and the peak ripples could be removed. With the reduction in demand, the similarity between the supply and demand curves was increased. This improvement in similarity factors is estimated to be 43.45% in summer and 11% in winter.

Energy conservation through this approach will also have positive impact of the environment by reducing the carbon emissions due to electricity generation. However, main focus of this paper is to quantify the impact of LED lamps on power demand and supply curves therefore other incentives of LED lamps have not been covered in detail.

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