ENERGY AUDITING AND OPTIMAL SOLUTION FOR SUPPLY-SIDE ENERGY MANAGEMENT OF A LOCAL BUILDING/COMMERCIAL FACILITY

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ABSTRACT:

The research focuses on the pivotal role of electrical energy in modern life, highlighting the need for sustainable, stable, and efficient supply, especially in India's energy landscape. Despite the growing integration of renewable sources, India heavily relies on thermal power, primarily coal-based, for about 75% of its energy generation. The paper explores the application of distributed resources for effective energy management and the economic analysis methods used in energy audits, such as the Payback method, Cost Savings, and Net Present Value. The research features case studies on energy audits of a micro grid at the A.I.T.S Rajampet and E.E.E Dept. loads in JNTUACEA, evaluating the potential of integrating solar and wind energy to reduce electricity costs. It demonstrates the economic feasibility of incorporating renewable resources and provides a comprehensive analysis of solar and wind energy sources and the economic impacts after integration.

Keywords: Electrical Energy, Energy Auditing, Distributed Resources (D.R), Micro Grid, Solar Energy, Wind Energy, Levelized Cost of Energy (L.C.O.E), Renewable Energy Integration, Payback Period.

I. INTRODUCTION :

India has experienced a significant rise in energy consumption due to its economic growth and development, emphasizing the crucial role of energy in the country's advancement. Electricity demand is on the rise as a result of rapid industrialization and population expansion in India's current energy landscape. Hence, there is a pressing need to address the challenges of energy inefficiency and excessive dependence on traditional power sources.

This research paper focuses on the critical importance of electrical energy in modern society and the pressing need for efficient and sustainable energy management practices, especially in India's context. Despite efforts to diversify the energy mix, about 75% of India's energy is still generated from thermal power plants, primarily coal-based, exacerbating environmental and economic challenges. The introduction emphasizes the global shift towards sustainable energy practices and underscores the urgency for countries like India to adopt renewable sources like wind and solar power to meet growing energy needs while mitigating environmental impacts.

Energy auditing is introduced as a vital tool for identifying areas of energy optimization, involving thorough examinations of energy flows in buildings or facilities to understand energy dynamics, pinpoint inefficiencies, and propose improvements. The Micro Grid at A.I.T.S Rajampet in Andhra Pradesh, India serves as a case study for applying these concepts, aiming to provide a comprehensive energy audit, assess energy consumption patterns, and efficiency levels, and explore renewable energy integration potential. Additionally, economic analysis methods used in energy audits, such as the Payback method and Internal Rate of Return, are discussed for evaluating the financial viability of energy efficiency measures and renewable energy projects. The introduction sets the stage for detailed case studies at A.I.T.S Rajampet and E.E.E Dept. in JNTUACEA, demonstrating the benefits of renewable energy integration in reducing energy costs.

By drawing insights from energy management handbooks [1]-[3], previous studies on energy monitoring [4], and energy conservation techniques in industrial settings[5], and also the implementation of energy audits following standards such as ISO 50002, as discussed by Larrahondo & Quispe in a bakery company [6], showcases the structured approach necessary for effective energy management. Such standards ensure a systematic evaluation of energy usage and help in identifying areas where renewable energy solutions can be integrated. The work by Simões et al. on electrical model development and validation for distributed resources [7] provides a technical perspective on integrating these renewable sources into the existing energy infrastructure.

Energy audits in educational buildings have been a subject of research, as highlighted in the study by Mohamed et al., which conducted an energy audit and conservation study at Princess Sumaya University for Technology [8], it emphasizes the importance of energy auditing in educational settings and provides insights into conservation strategies that can be applied to improve energy efficiency. Mathews and Botha [9] discuss the significance of Building Management Systems in enhancing energy efficiency, as highlighted in their paper published in Energy and Buildings.

In Asimakopoulos [16], the intricate relationship between energy use and climate impact in urban built environments was discussed, emphasizing the importance of implementing energy-efficient practices. Goswami & Kreith [17] provide insights into energy efficiency and renewable energy, offering valuable information on sustainable practices applicable to commercial buildings. Their handbook serves as a comprehensive guide for understanding renewable energy technologies and their integration into building energy systems.

In the context of sustainable energy solutions, Bundschuh & Chen [18] highlight the significance of adopting environmentally friendly agriculture practices. While their focus is on agricultural settings, the principles of sustainable energy solutions can be extrapolated to commercial buildings to optimize energy management strategies. Furthermore, the integration of renewable energy sources into power systems is crucial for supply-side energy management. Studying Shapiro's work [19] offers thorough insights into energy audits and effective strategies aimed at enhancing energy efficiency within commercial building structures. The article "Renewable energy in power systems" [20] illuminates the role of renewable energy in enhancing the resilience and sustainability of power grids, directly relevant to optimizing energy solutions in commercial buildings.

In, ASHRAE [21] provides valuable insights into energy-efficient design strategies for commercial buildings. Kenney [22] explores energy conservation in industrial processes, stressing the importance of efficient energy utilization. By applying energy conservation principles from industrial settings to commercial buildings, significant improvements in energy efficiency and cost savings can be achieved.

OBJECTIVE:

The main objectives of this research are:

- To reduce the average cost of energy (per unit cost/COE).
- To implement renewable resources as viable resource options.
- To calculate and compare the payback period, and cost of energy for solar and wind energy resources.

II. METHODOLOGY :

This section outlines the process and approach used in conducting energy audits, including the steps and techniques involved.

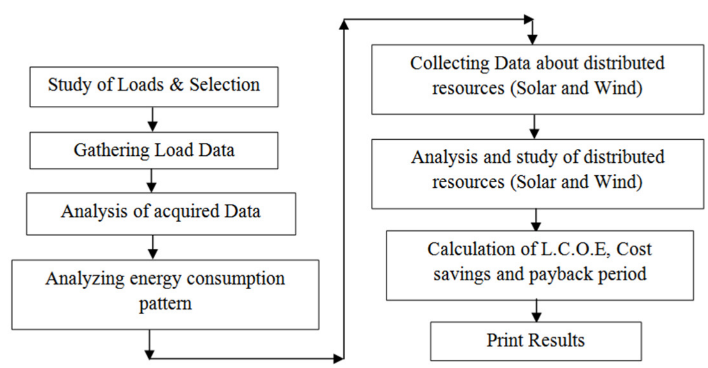

Fig .1: Flowchart for energy audit

An energy audit is a systematic approach to understanding and reducing a facility's energy consumption, reducing cost of energy, and identifying cost-saving opportunities.

In Other words, an energy audit is a detailed and methodical process that encompasses everything from initial data gathering to the implementation of energy-saving measures and their ongoing monitoring. It's a critical tool for organizations looking to reduce their energy consumption, lower costs, and improve their environmental footprint.

Before the selection of load, one must do thorough research about the energy audit and the process involved from the planning to the report submission of the audit. In this work, a process, which involves the following steps, is conducted on two different types of loads with the help of a MATLAB algorithm for the calculation part of the process.

- ❖ **Study of Loads & Selection**: The first step involves studying different types of loads and selecting the load for the energy audit.
- ❖ **Gathering Load Data**: In this step, data is collected from the main electrical department staff with the permission of higher authorities. The data includes hourly, daily, monthly, and yearly load demand changes along with the total connected load and their rated parameters.
- ❖ **Analysis of Acquired Data**: The collected data is analyzed to understand the energy usage and energy balance of the facility.
- ❖ **Analyzing Energy Consumption Pattern**: This involves hourly analysis of the load demand data to recognize patterns in load demand changes throughout the day. This step helps in determining which type of distributed resource can be used/recommended in addition to the grid to reduce energy costs.
- ❖ **Collecting Data about D.R.s**: After determining feasible resources for implementation, data about these resources are collected from practical sources or estimated data from manufacturers.
- ❖ **Analysis of Distributed Resources**: A detailed analysis is conducted on the data of the selected resources to ensure that the implementation results in the lowest energy cost possible while maintaining other parameters in an affordable range.
- ❖ **Calculation of L.C.O.E, Cost Savings & Payback Period**: An algorithm is prepared to help calculate the Levelized Cost of Energy (L.C.O.E), cost savings, and payback period with the grid and respective resources.
- ❖ **Print Results**: The final step involves documenting the entire process and its results, tabulating the parameters like L.C.O.E, cost savings and payback period.

Algorithm:-

Step 1: Enter Grid data (total connected load), contract demand and total load over the year.

Step 2: Enter tariff rates per KWh (unit).

Step 3: Average electricity bill per month for the grid is calculated as per tariff rates.

Step 4: Enter the number of available resources considered and their types.

Step 5: Enter input quantities related to the type of resource considered i.e., rated power, capital cost, maintenance cost, total units generated over the year, expected life span and no. of hours operated per day.

Step 6: Calculations of total energy over the period and its cost, L.C.O.E (per unit cost), savings in cost, payback period.

Step 7: Repeat steps 5 and 6 for as many resources as entered in step 4.

Step 8: Print the results

Step 9: Stop

In this work, the period is considered as a year and the following equations are used for calculating energy costs, per unit cost and payback period.

Formulas Used:-

Total Energy over the period (T.E)

$$= \sum_{i=1}^{i=8760} Pi \times Ti \quad (1)$$

Total energy cost over the period

$$= \text{Total energy} \times \text{per unit cost} \quad (2)$$

Levelized Cost of Energy (L.C.O.E) =

$$\frac{\text{Total costs included over the life span}}{\text{Total Energy produced over its life span}} \quad (3a)$$

(Or)

$$\text{L.C.O.E} = \frac{\text{Capital Costs} + (\text{Maintenance \& Operational Costs} \times \text{Lifespan})}{\text{Total Energy Produced Over the year} \times \text{Life span}} \quad (3b)$$

Savings over the period =

$$\text{Total energy} \times (\text{Grid unit cost} - \text{resource L.C.O.E}) \quad (4)$$

$$\text{Payback period} = \frac{\text{Total energy cost}}{\text{Life span} \times \text{Savings over the period}} \quad (5)$$

Where, T.E = Total Energy over the period

P_i = Load Demand at i^{th} hour

T_i = Operated time of load at i^{th} hour

L.C.O.E = Levelized Cost of Energy

Here, the calculation of L.C.O.E is the ratio of total cost of the system and the energy produced over the period, Eqn (3) is used if the total costs and total energy produced, of the resource, over its lifespan is known, similarly Eqn (3a) is used if we know the different parameters i.e., capital costs, maintenance & operational costs and life span.

In both case studies, the total period of 1 year is divided into three seasons one is summer, one is rainy and other is winter seasons, and their corresponding parameters such as solar irradiance, ambient temperature, wind speed, at the location where case study-1 load is situated, are represented as a comparative graphs below.

Figure 2 represents a detailed analysis of solar irradiance variations and ambient temperature across different times of the day throughout different seasons of the year of the same location where the Load is considered. This graph is crucial for understanding the availability and intensity of solar energy, studying environmental and climatic patterns across various times of the day during different seasons. It helps in determining the most effective periods for solar energy generation, which is essential for integrating solar power into the overall energy mix effectively. Understanding these temperature fluctuations is also crucial for designing HVAC systems, as it informs the required heating and cooling needs for different times of the year. The graph helps in anticipating seasonal impacts on energy consumption and environmental conditions, playing a key role in planning and decision-making processes related to environmental management and sustainable practices.

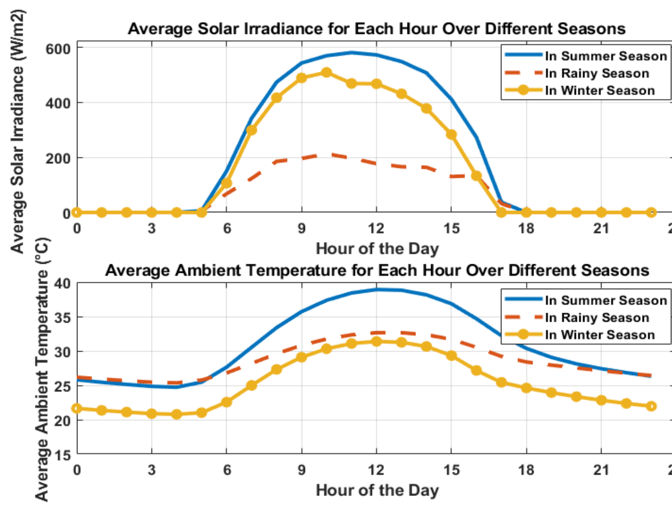

Figure 2: Average solar irradiance and ambient temperature for each hour over different seasons

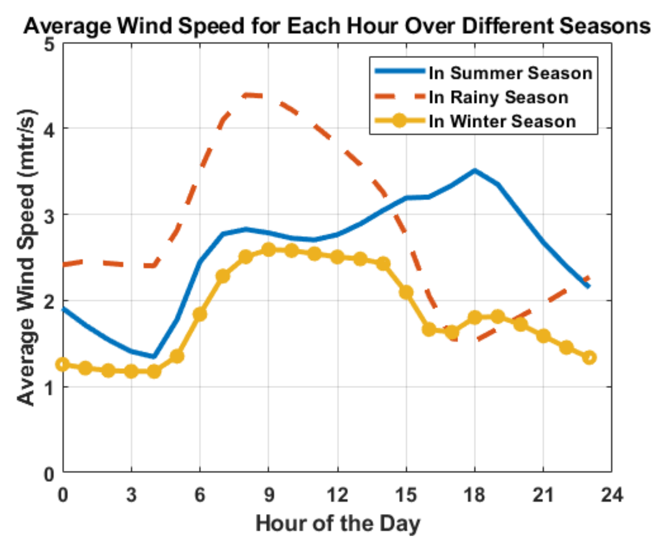

Figure 3: Average wind speed for each hour over different seasons

Figure 3 is an insightful graph that illustrates the variation in wind speeds throughout the day across different seasons. This graph is essential for understanding how wind conditions change, which is critical for applications like wind energy generation and environmental studies. By providing hourly wind speed data across seasons, it helps in assessing the feasibility and efficiency of wind power projects, guiding the design and placement of wind turbines, and predicting energy output. It's also valuable for weather-related research and planning in various sectors.

III. RESULTS & DISCUSSION:

In this work, two case studies were carried out. The first one is at the A.I.T.S, Rajampet, Andhra Pradesh., focusing on a 1KW load of ceiling fans and tube lights. The second case study investigates the load of the E.E.E. Dept. in JNTUACEA, including lighting, A.C., and motor loads. Both case studies are evaluated to check the potentiality of integrating solar and wind energy to reduce electricity costs.

CASE STUDY 1:

Analysis of a 1KW Micro grid in Annamacharya Institute of Technology & Sciences, Andhra Pradesh:

This case study focuses on a smaller-scale energy system of 1KW micro grid, which includes light loads i.e., ceiling fans and tube lights.

The key aspects of this case study are:

❖ **Load Data**: The total connected load is 1KW, with an annual total load demand of 2377.55 KW, averaging 6.15 KW per day and 198.13 KW per month.

Figure 4 represents the daily load demand fluctuations for 24 hours over a year. Which is divided and compared between three seasons summer, rainy and winter seasons i.e., data from 3rd, 4th, 5th, 6th months are considered under summer, similarly 7th , 8th, 9th, 10th months are considered under rainy and 11th, 12th, 1st , 2nd months are considered under winter season.

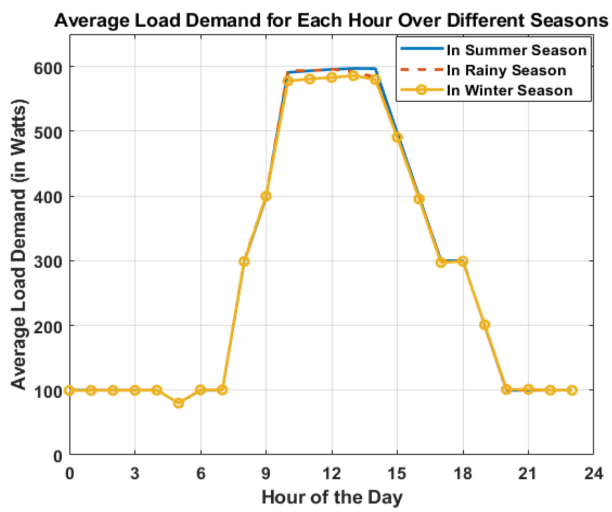

Figure 4: Average Load Demand graph for 24 hours.

The average load demand of these months are calculated and plotted under the respective curve.

The graph is an essential tool for analyzing energy consumption patterns within the studied facility and provides a visual representation of the load variations, highlighting peak and off-peak hours. This information is crucial for energy management, allowing for the identification of times when energy demand is at its highest and lowest.

The average monthly electricity bill for this grid is calculated at Rs. 1615.569, with an average cost of Rs. 8.15 per unit using the above-mentioned algorithm.

Two Resources, one is Solar and the second is wind, are considered as the distributed resources with which we determined the cost analysis and respective payback periods.

❖ **Solar Resource**: A solar system with a rated power generation of 1KW was analyzed.

The main components of a 1kW solar system are Shark 445W * 2 solar panels, 2500VA, 24V * 1 MPPT-based solar inverter, 150Ah * 2 solar batteries and a solar installation kit.

(https://www.loomsolar.com/blogs/pricelist/1kw-solar-system-price-in-india)

The capital cost for this system was Rs. 110,000, and it was estimated to generate 1446.883 KW over the year, operating 12 hours per day.

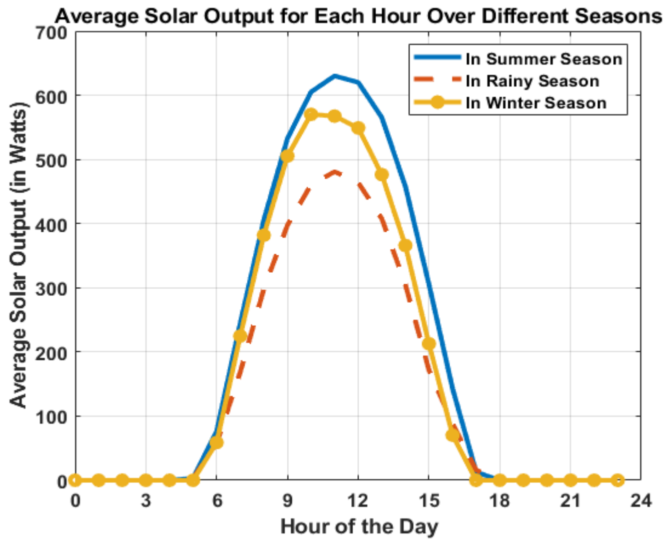

Figure 5: Average Solar output for each hour over different seasons

Figure 5 is a detailed graph that showcases the variation in solar output across different seasons, analyzed on an hourly basis over a period of 24 hours. In this graph, it is observed that the solar output reaches its maximum during 10th to 12th hour of the day.

The L.C.O.E for solar was calculated as Rs. 3.04 per unit. The annual cost savings from the solar system amounted to Rs. 7296.72, with a payback period of 15.08 years.

❖ **Wind Resource**: A wind system with 1.5KW rated power was also considered.

This had a capital cost of Rs. 150,000 and was expected to generate 1522.92 KW annually, operating 24 hours per day.

Figure 6 depicts the average wind energy production across various seasons, analyzed hourly. This graph is vital for understanding how wind energy potential varies with time and season, crucial for wind power planning and management. It aids in assessing the reliability and effectiveness of wind power generation in different seasonal conditions,guiding the design and implementation of wind energy systems for optimized performance.

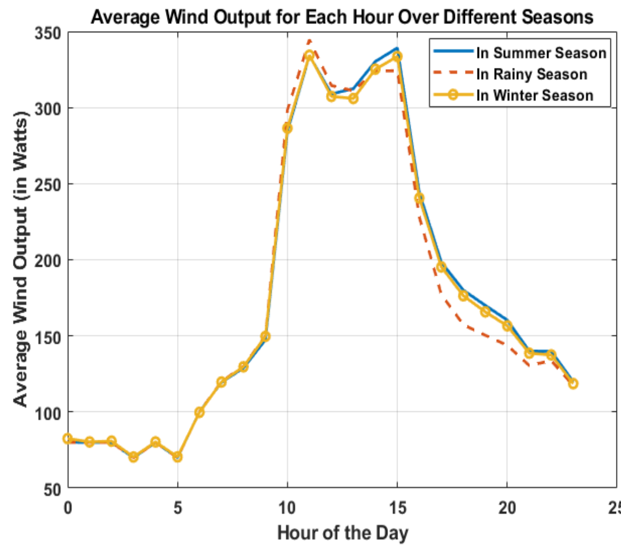

Figure 6: Average wind output for each hour over different seasons

The L.C.O.E for wind was Rs. 3.94 per unit. The wind system's annual cost savings were calculated at Rs. 6330.15, with a payback period of 23.70 years.

Table 1: Resource Parameters for 1st case study

Parameters	Solar	Wind
Rated Power (KW)	1 KW	1.5 KW
Capital Cost (Rs.)	Rs. 1,10,000	Rs. 1,50,000
Total Units Generated over the year (KW)	1446.883KW	1522.92 KW
No. of Hours Operated per day (hrs)	24	24
Life Span (Years)	25	25

The parameters for the Distributed resources such as Rated power, capital cost, energy generated per year, operated hours per day and life span are tabled in table 1.

Table 2: Calculations of Total Energy, L.C.O.E, savings, energy costs for each D.R and combined

	Without renewable resources	**With renewable resources**		
		Solar	**Wind**	**Both**
Load supplied/year (in KW)	2377.55 **KW**	1446.88 **KW**	1522.92 **KW**	2377.55 **KW +** nearly 500 KW reserve
Capital Cost (in Rs.)	_	1.1 Lakhs	1.5 Lakhs	2.6 Lakhs
No. of hours operating	24 hrs	12hrs	24hrs	24hrs
Life span	Lifetime	**25** Years	**25** Years	**25** Years
Electricity bill / month	**Rs.** 1615.569	**Rs.** 1,007.51	**Rs.** 1,088.059	**Rs.** 480
Total energy cost/year	**Rs.** 19,386.828	**Rs.** 12,089.28	**Rs.** 13,056.678	**Rs.** 5760
L.C.O.E (in Rs.)	**Rs.** 8.15	**Rs.** 3.04	**Rs.** 3.94	**Rs.** 3.49
Cost savings per Year	0	**Rs.** 7296.72	**Rs.**6330.15	**Rs.** 13626.87
Pay Back Period (Years)	0	**15.08** Years	**23.70 Years**	**19.39 Years**

The calculations obtained from the algorithm are organized in the above table, from the table 2 it is observed that the total energy cost without using renewable resources is higher than that of each renewable resource. Per unit cost (L.C.O.E) is considerably lower for solar (Rs.3.04) than any other resources, and a little bit higher for wind (Rs.3.94) and it is Rs. 3.49 for both combined. The cost savings are higher in solar, due to its lowest L.C.O.E, and a little bit less for wind. The payback period is reduced when both resources are implemented than that of the individual implementations i.e., for only solar it is 15.08 Years, for only wind it is 23.70 Years and when both combined the payback period is reduced to 19.39 Years.

CASE STUDY 2:

Analysis of 421.72 KW Load in E.E.E Dept. at JNTUACEA:
This case study escalates in scale, examining a significant energy load in an academic department:

- **Load Data**: The total connected load was considerably larger than the load in case study 1 i.e., 421.72 KW.

The annual load demand was 151.11 MW, with an average daily demand of 414 KW and a monthly demand of 12,420 KW.

The average monthly electricity bill for this load was Rs. 129,371.375, at an average of Rs. 10.2737 cost per unit.

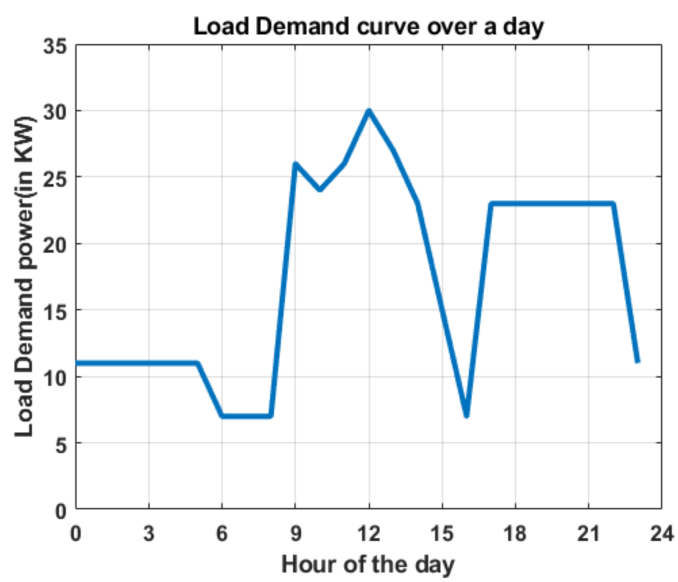

Figure 8: Average Load demand graph for each hour over a day

Figure 3 illustrates the hourly variations in load demand throughout a typical day. This graph is instrumental in understanding the dynamic nature of energy consumption, providing detailed insights into how load demand changes every hour. It is particularly useful for identifying specific hours with unusually high or low energy demands, which is crucial for effective energy management.

This hour-by-hour analysis allows for a more granular understanding of energy usage patterns, aiding in the development of tailored strategies to optimize energy consumption and reduce costs, particularly in peak demand hours.

- **Solar Resource**: Similar to the first case study, a 50KW solar system was analyzed. The capital cost for this system was Rs. 27,00,000 and was expected to generate 240 to 250 units per day i.e., 91,250 KW over a year, operating 12 hours per day.

The L.C.O.E for solar was Rs. 1.18 per unit. The annual cost savings from the solar system amounted to Rs.828831.75, with a payback period of 3.26 years.

- **Wind Resource**: A wind system with 50KW rated power was considered. This had a capital cost of Rs. 61,00,000 and was expected to generate 75,000KWh annually, operating 24 hours per day.

The LCOE for wind was Rs. 3.25 per unit. The wind system's annual cost savings were calculated at Rs. 528125.17, with a payback period of 11.55 Years.

Similar to the first case study, two renewable resources are considered as the distributed resources, one is Solar and the second is wind, with which we determined the cost analysis and respective payback periods as tabled below.

Table 3: Resources Parameters for 2nd case study

Parameters	Solar	Wind
Rated Power (KW)	50 KW	50 KW
Capital Cost (Rs.)	Rs.27,00,000	Rs. 61,00,000
Total Units Generated over the year (KW)	91250 KW	75000 KW
No. of Hours Operated per day (hrs)	24	24
Life Span (Years)	25	25

The calculations obtained from the algorithm, for the second case study, are organized in the above table, from the table 4, Similar to the case study 1; the total energy cost is higher when only grid is used. Per unit cost (L.C.O.E) of solar is significantly lower (Rs.1.18) than any other resources, and a little bit higher for wind (Rs.3.25) and Rs. 2.215 for both resources combined. The cost savings are higher for solar, due to its lowest L.C.O.E, and a little bit less for wind. The payback period is reduced when both resources are implemented than when each resource is used individually i.e., for only solar it is 3.26 Years, for only wind it is 11.55 Years and when both combined the payback period is reduced to 6.481 Years.

Both case studies effectively demonstrate the financial and operational implications of incorporating solar and wind resources into different scales of energy systems. They highlight the potential for significant cost savings and emphasize the importance of considering the initial investment and payback periods when implementing renewable energy solutions in both small and large-scale settings.

Table 4: Calculations of Total Energy, L.C.O.E, savings, energy costs for each D.R and combined

	Without renewable resources	With renewable resources		
		Solar	Wind	Both
Load supplied per year (in KW)	1,51,110 **KW = 151.11 MW**	91,250 **KW = 91.25 MW**	75,000 **KW = 75 MW**	151 **MW +** nearly 15MW reserve
Capital Cost (in Rs.)	_	27 Lakhs	61 Lakhs	88 Lakhs
No. of hours operating	24 hrs	12hrs	24hrs	24hrs
Life span	Lifetime	**25** Years	**25** Years	**25** Years
Estimated Electricity bill /month	**Rs.** 1,30,871.375	**Rs.** 61,802.065	**Rs.** 86,860.945	**Rs.** 17,791.635
Total energy cost / year	**Rs.** 15,70,452	**Rs.** 7,41,620.25	**Rs.** 10,42,327	**Rs.** 2,13,495.08
L.C.O.E (in Rs.)	**Rs.** 10.3928	**Rs.** 1.18	**Rs.** 3.25	**Rs.** 2.215
Cost savings per Year	**0**	**Rs.** 8,28,831	**Rs.** 5,28,125	**Rs.** 13,56,956
Pay Back Period (Years)	0	**3.26** Years	**11.55** Years	**6.481** Years

IV. CONCLUSION:

In conclusion, a certain type of process conducted on two systems, A.I.T.S, Rajampet and E.E.E Dept. in JNTUACEA, Andhra Pradesh, India, results in substantial opportunities for cost savings, reduced per unit cost and reduced reliance on non-renewable energy sources. In both the systems, combined usage of resources i.e., solar and wind, reduces the total energy costs, increasing the cost savings, reduced per unit cost and payback period.

In the first case study, the solar & wind resources showing a savings of **Rs. 7,296.72**/year & of **Rs.6,330.15**/year, payback period of **15.08** Years & **23.70** Years respectively. But in the second case study, the solar & wind resources show savings upto **Rs. 8,28,831**/year & **Rs. 5,28,125**/year, payback period of **3.26** Years & **11.55** Years respectively. From studies the increased savings and decreased payback period in the 2nd case study is due to its higher load demand capacity, when compared to the first case study. The average unit costs of energy before implementing Renewable resources are **Rs.8.15** and **Rs.10.3928** which is reduced to **Rs.3.49** and **Rs.2.215** after implementing Renewable resources for 1st and 2nd case studies respectively.

This work provides a comparative analysis between two different sized commercial facilities and respective economic benefits by implementing renewable resources like solar and wind resources. It is evident that transitioning to renewable energy sources is not only environmentally responsible but also economically feasible, offering a pathway to a more sustainable and cost-effective energy future for India and similar regions.

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