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Study of Grid Integrated SPV System

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Abstract:

The increasing global demand for clean and sustainable energy sources has propelled the widespread adoption of solar photovoltaic (PV) systems. This study focuses on the integration of solar PV systems into the grid to meet electricity demands efficiently while minimizing environmental impact. The Hybrid Optimization of Multiple Energy Resources (HOMER) software is employed as a powerful tool for the techno-economic analysis and optimization of the grid-connected solar PV system. The research begins with a comprehensive review of solar energy technologies and their integration challenges with the existing electrical grid. HOMER, as a simulation and optimization tool, is utilized to model the solar PV system's performance by considering various parameters, such as solar irradiance, system configuration, and grid interactions. The objective is to achieve an optimal design that balances energy production, cost-effectiveness, and environmental sustainability. Key aspects of the study include the evaluation of different solar PV technologies, system sizing, and the impact of geographical location on the system's performance. The results obtained through HOMER simulations are analyzed to identify the optimal configuration of the solar PV system in terms of capacity and grid interactions. The economic viability and environmental benefits of the proposed system are assessed, considering factors such as levelized cost of electricity (LCOE) and greenhouse gas emissions. This work contributes valuable insights into the design and optimization of grid-integrated solar PV systems, offering a roadmap for sustainable electricity production in Ladakh of India.

INTRODUCTION

Energy is the most basic essential for human survival. The energy must be safe and secure, with a suitable supply for the current circumstances. The pattern of energy usage and the demand for energy will increase in the near future [1]. Energy exists in numerous forms, including mechanical energy, nuclear power, electrical energy, hydro energy, and so on. Of all types of energy, electrical energy is the most well-known due to its ease of use and transfer over long distances. In contrast to other forms of energy, it is not needed that energy be created (changed) and used in the same location [2].

Renewable energy systems (RESs) have grown in favor since they are limitless, environmentally safe, solid, productive, and offer clever features that can serve load. Furthermore, sustainable energy has a bright future and a stable global climate, and it is regarded as an excellent way for dealing with ecological problems [3-5]. PV panels generate clean, efficient power. There are no harmful ozone depleting material discharges during power generation using PV boards, hence sunlight-based PV is safe for the environment. Solar energy is energy that is given naturally - it is thus free and abundant. It creates energy where there is insolation. The energy can be used to power grid-connected networks. In many ways, this energy is the most dependable and sophisticated. Furthermore, the cost of solar-powered chargers is falling and is predicted to continue falling in the next years - hence, solar PV panels have an extraordinarily hopeful future both financially and environmentally [6]. However they suffer the nature of intermittency which can be overcome by integrating such sources with another energy sources.

The national system can deliver electricity 24 hours a day, seven days a week and 365 days in a year. But due of topographical obstacles, it is difficult for the grid to deliver continuous power to several regions of India. The power distributed in that location is of very low quality, with frequent outages, making supply reliability an issue. Because of the restricted movement of personnel and equipment in severe environments, supply and reliability suffer substantially.

On the other side, renewable energy sources installed on the installation site can avoid such challenges. Solar PV can fix this problem, however it has intermittent qualities. Some storage devices, like as batteries, can be utilized, but this will affect the environment and increase the cost of the model. To address this issue, the national grid is being connected with the Solar PV paradigm to create a sustainable paradigm.

The electricity generated by the SPV system will be used largely for supplying electricity to the community's demand. Excess electricity is sold to the grid after fulfilling need of the locality. During an electrical energy production shortfall, the necessary electricity will be acquired from the grid. The system incorporates a net metering system as well as power purchase and sale at a predetermined price. The above power production and supply scheme is conceived for a local load in Leh Ladakh.

Thus, the current work intends to link solar PV with the national grid and examine the hybrid option for dependable and cost-effective power delivery.

LITERATURE REVIEW

According to Dondariya et al. (2018), a solar rooftop PV system is an appealing alternate power source for families. Solar PV potential for a specific site may be assessed using software simulation tools. This research is being conducted to determine the viability of a grid-connected rooftop solar photovoltaic system for a domestic building in the holy city of Ujjain, India [7]. Mama et al. (2013) investigate the consequences of a true remote PV model on a Hong Kong island. The outcomes of system watching and assessment provide a detailed research of system functioning execution concerning specialized concerns [8]. Liu et al. (2013) offer the review, which continues to study the underlying impediment and major elements influencing sustainable power use in Taiwan structures. In addition to providing references to essential ecological energy systems for arrangement and inventive work, it also allows developing and immature nations access to applications of solar energy innovation assessment and forecasts for the future [9]. Praveenkumar et al. (2022) noted how India is one of the world's most populous countries, which has ramifications for its energy usage. This study evaluated the techno-economics and environmental effect of a solar photovoltaic power plant for both electricity and hydrogen generation in five major Indian cities (Chennai, Indore, Kolkata, Ludhiana, and Mumbai) [10]. Mama et.al (2015) analyzes a few force supply choices, for example, sustainable power and diesel power age thinking about one distantly found local area. A techno-financial investigation and a point by point hourly reenactment were performed to track down an ideal independent systems setup [11]. According to Jain et al. (2022), increased energy demands and obligations related to climate change have hastened the deployment of solar power globally, particularly in India. After reviewing existing global methods, it goes on to suggest a legislative framework targeted at mainstreaming end-of-life (EOL) management of solar PV waste in India [12]. Navamani et al. (2023) examine the performance of a 140-kW grid-connected photovoltaic (PV) plant erected on the roof of an aerospace hangar block at the SRM Institute of Science and Technology in Kattankulathur, Tamil Nadu, India [13]. Pancker et.al (2023) observed that Building Applied Photovoltaics (BAPV) such as Roof-top Solar PV has attracted substantial attention in recent years for tapping the untapped potential of renewable energy sources The purpose of this research is to develop and evaluate the feasibility of an integrated grid-connected Rooftop and Façade Building Integrated Photovoltaic (BIPV) system for addressing the energy demands of residential buildings on an academic campus [14]. Prajapati et al. (2023) stated that we have been using traditional methods for electricity generation for a long time. Existing energy facilities are losing dependability in meeting load needs as demand rises. This research discusses performance analysis and CO2 emission reduction for an on-grid system [15]. Kumar et.al (2023) discussed that rooftop solar PV in India has experienced considerable growth in the commercial and industrial sectors, but progress in the household sector has been rather modest due to the high initial installation cost. As a result, robust market models for Rooftop Solar (RTS) deployment are required. This research compares viable RTS market models using the discounted cash flow approach, in accordance with new regulatory rules [16].

ENERGY BALANCE EQUATION [17]

The energy balance equation is given as follows, where Ein is the Energy IN the System and Euse is the Energy Used:

$$E_{in} = E_A + E_{BU} + E_{FUN} + E_{FSN} \quad (1)$$

$$E_{use} = E_L + E_{TUN} + E_{TSN} \quad (2)$$

where EFUN and ETUN are, respectively, the Net Energy FROM and To the Utility, and EFSN and ETSN are, respectively, the Net Energy FROM and To the grid, as defined in the IEC-61724 Standard. EA, EBU, the net energy from Array generation and Back-Up source respectively and EL represents the Energy to the Load.

SIMULATION METHODOLOGY

The national renewable energy laboratory (NREL) apparatus developed by the United States (US) is used in this work for exhibiting and generating purposes, as is the hybrid optimal model for electric renewables (HOMER) programming [18]. This is a frequently used programming in various combinations of source in various sites. It is a versatile device that models a blend of common fills and sustainable power to determine the most practicable arrangement for any framework. The following information data will be provided in HOMER: electric load (essential energy), renewable source (sun powered radiation), hydro assets, part specialized subtleties/costs, dispatch mechanism, and so on [19].

DESIGNING ASPECT OF THE MODEL

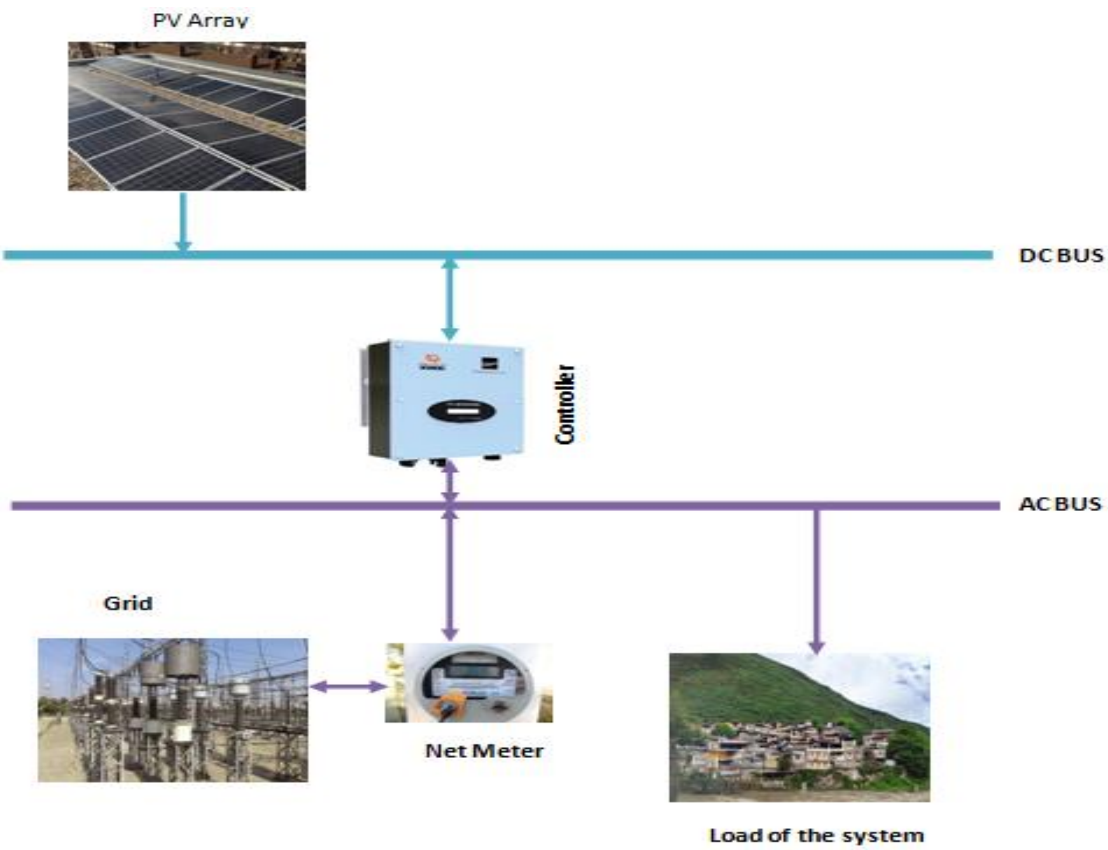

Fig.1. Proposed Model

The operation of the solar-powered PV-Grid-integrated system is briefly depicted above. The sun-powered PV exhibit is the plan's primary energy producer, and it is meant to meet the nearby burden need. When there is an oversupply of energy, it is supplied to the framework at a predetermined cost, and when there is a scarcity of force, it is purchased from the lattice. Net meter calculates the difference and recommends a monthly payment plan. As a result, a consistent and reasonable energy supply would be assured 24 hours a day, seven days a week.

The essential parts of the framework is PV array, national grid, network balance equipment as inverter, net meter and regulator.

STUDY OF LOAD PATTERN

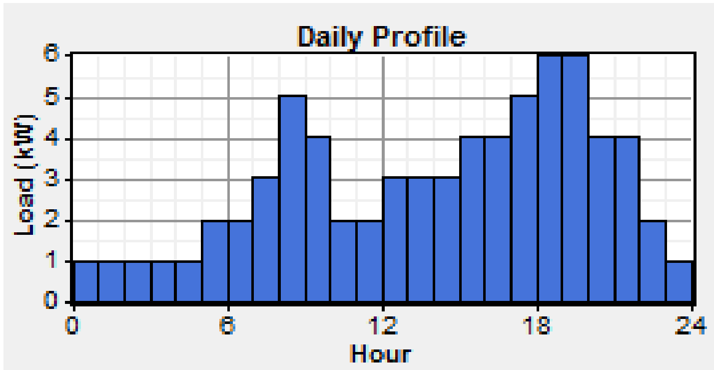

Fig.2. Daily load Variation

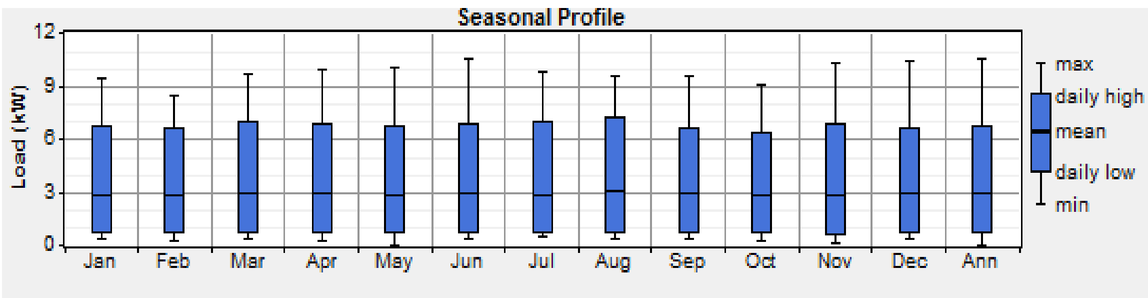

Fig. 3. Seasonal load profile

The suggested structure is designed to handle a daily load of 69 kWh and a peak load of 11 kW. This, in any event, addresses the typical load. The system is too capable of manage the future load upto 10% from the current profile without altering the present structure. The system is deigned to cater the need of mainly domestic loads. Peak load on the system appears during evening hours. The grid integration mainly aims to provide electricity during night, as the PV does not operate during absent of insolation. The load is synthesised by the HOMER, with a peak of 11 kW and a daily energy usage of 69 kWh noted. However, seasonal volatility is kept to a minimum in order to keep the load profile simple.

SOLAR ENERGY RESOURCE

PV energy is a key component of the proposed strategy. PV energy generation is rising with each passing day. Many variables influence PV power generation, including the operational climatic condition. The average quantity of solar radiation in India is 4-6 kWh/m2/day. The longitude is 74.45 degrees and the slope is 34.35 degrees. Furthermore, the suggested limit of the PV exhibit is 25 kWP for the proposed site's month to month average daily solar radiation of 5.482 kWh/m2/day with a clearness record of 0.656.

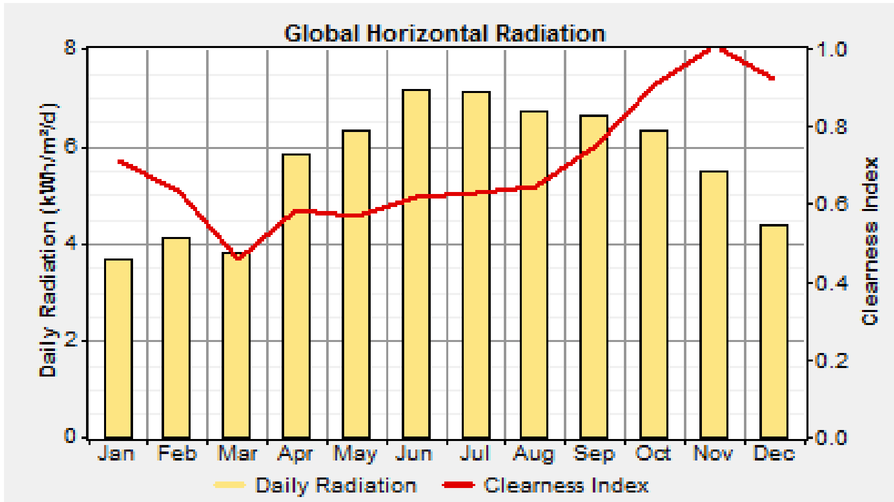

Fig.4. Solar energy resources

NATIONAL GRID

The cost of selling and collecting energy by the matrix from the framework is just included in the framework for simplicity. There are no additional charges because the Grid is already in place. The hybrid structure purchases power at INR 9.80/kWh and sells it at the same rate. The buyback REPO arrangement is considered here.

MONTHLY POWER OUTPUT FROM PV ARRAY

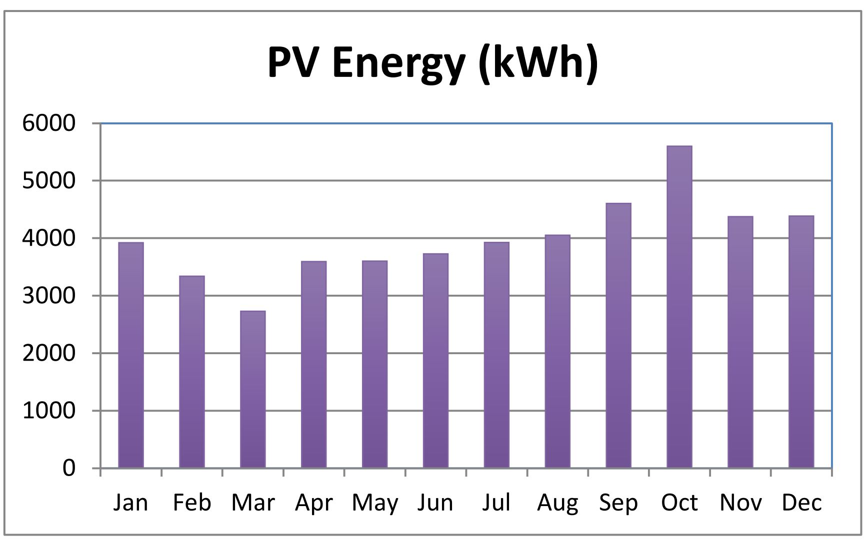

Fig. 5. Monthly power output from PV array

The graph above depicts the monthly variance in PV array yield. It can be seen that the yield from the SPV is steady and peaks between September and November. So, PV can create a considerable quantity of energy during that time frame. The presence of clouds reduces energy generation in the month of March. The SPV's annual energy production is predicted to be 47,837 kWh.

GRID SUPPLY

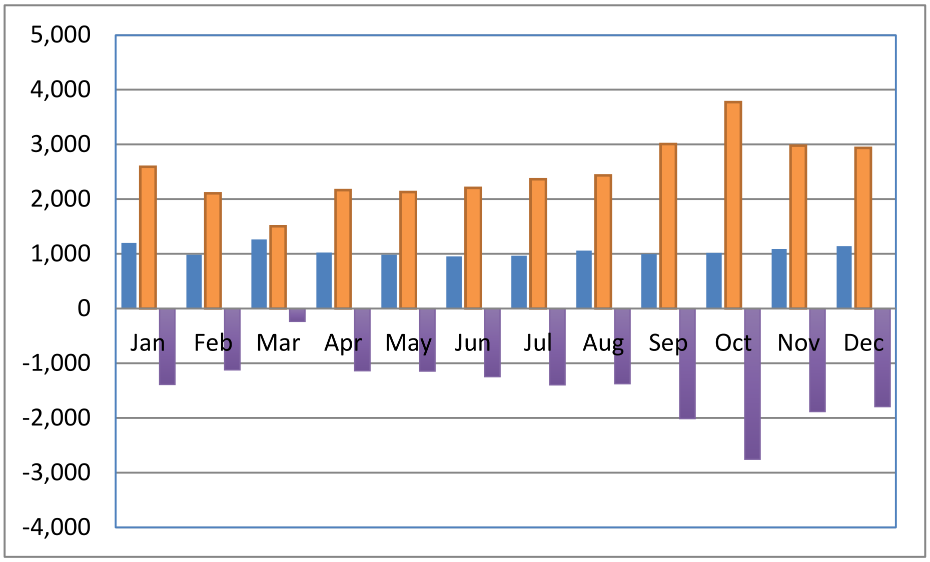

Fig.6. Monthly power output from PV array

The study makes the assumption that the grid expansion was present. The interaction is noticed as the hybrid system is connected with the current grid. Because the system eliminates the use of batteries due to environmental concerns, the grid connection is assumed to improve dependability. The grid is linked to the solar PV system via net metering to compute the incoming and outgoing electricity. The system observes that the total outgoing energy in a year is 30,205 kWh, which is the energy sold, and the total incoming energy is 12,701kWh, which is the energy created in the observed year. A total of 17,505 kWh of energy is net sold to the grid, according to the system. The orange bar shows the energy sold to the grid, the blue bar shows the energy purchased and the net effect of the interaction is shown by the violet bar.

RENEWABLE PENETRATION LEVEL

The proposed scheme's novelty is the degree of renewable penetration attained. Solar photovoltaic panels is used to generate power in the proposed design. However the energy the system consumed from the grid is not pollution free. The renewable energy penetration is 79%. However the system suggest that the system can able to deliver net power to the grid, so the scheme in actually becomes a savior of the environment, by in putting more energy to the grid.

ENERGY CONSUMPTION PATTERN

The proposed site's power usage is anticipated to be 69 kWh/day. The figure below depicts an example of a load profile for four different seasons. The 10th of February is viewed as a typical day that symbolizes the spring season; similarly, the 10th of April represents the summer season; and the 10th of August signifies the monsoon season. The typical winter load is represented on December 10th. The blue line represents the variance in average load during the spring season, while the red, green, and violet lines represent the average load throughout the summer, winter, and monsoon seasons, respectively.

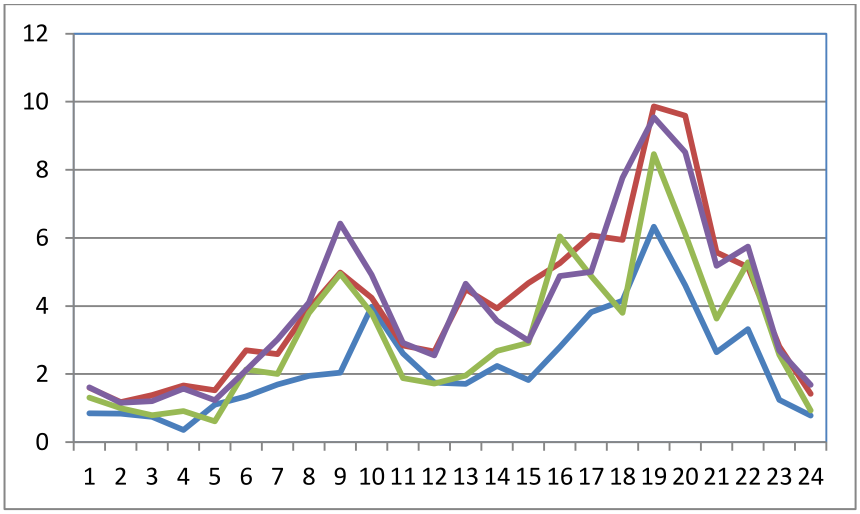

Fig.7. Seasonal variation of estimated load

VARIATION IN ENERGY WITH DEMAND

The daily average power generation from PV is represented in orange, the grid is indicated in green, and the average demand is shown in blue line. After fulfilling the local load demand, the electricity is delivered to the grid for sale at a predetermined price in order to produce some revenue from the project. The graphic indicates a bigger margin of production in relation to the load demand that arises on each day.

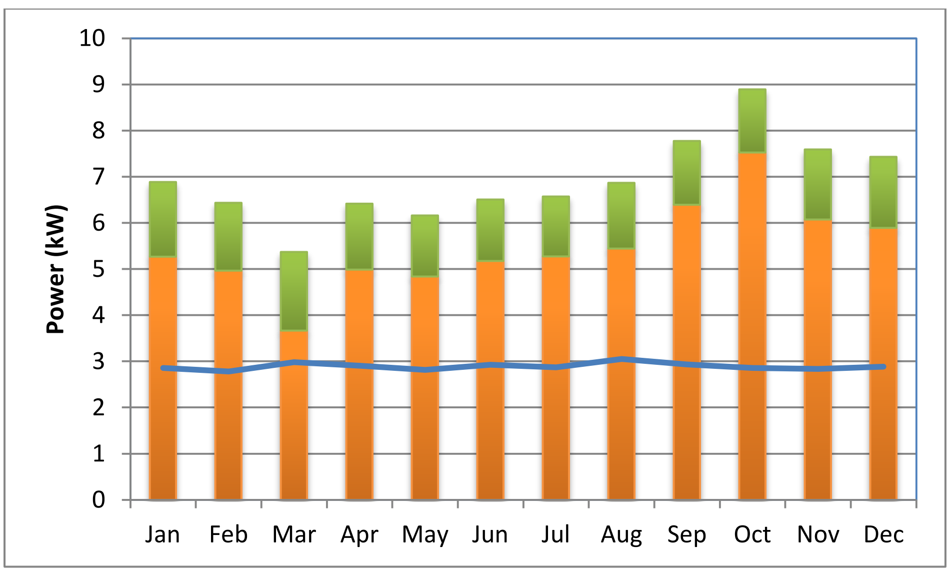

Fig.8. Daily energy production and load demand

CONVERTER PERFORMANCE

The inverter is the system's main point of failure; its functionality is necessary solely while converting PV electricity to DC power. However, the modeling indicates that the inverter must be operational for around 4385 hours every year. The two images below represent the inverter's working characteristics; it can be seen that from August to December, the converter operates at a high efficiency, and the inverter plays an important role throughout the year.

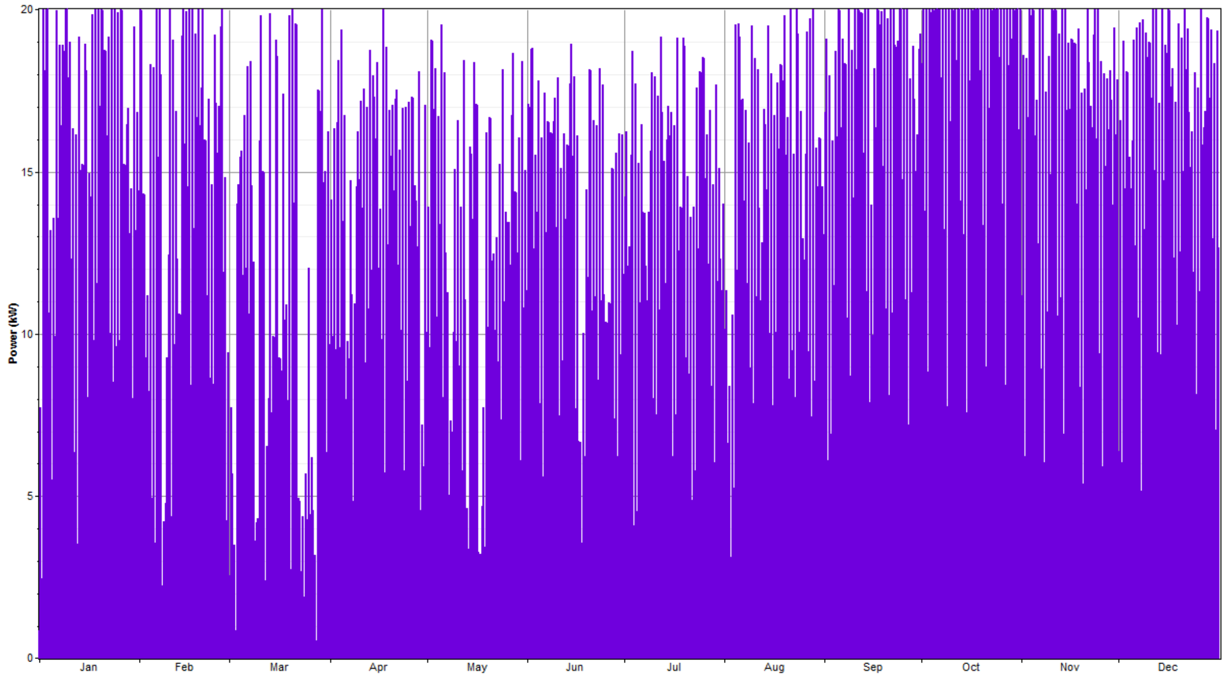

Fig.9. Inverter performance

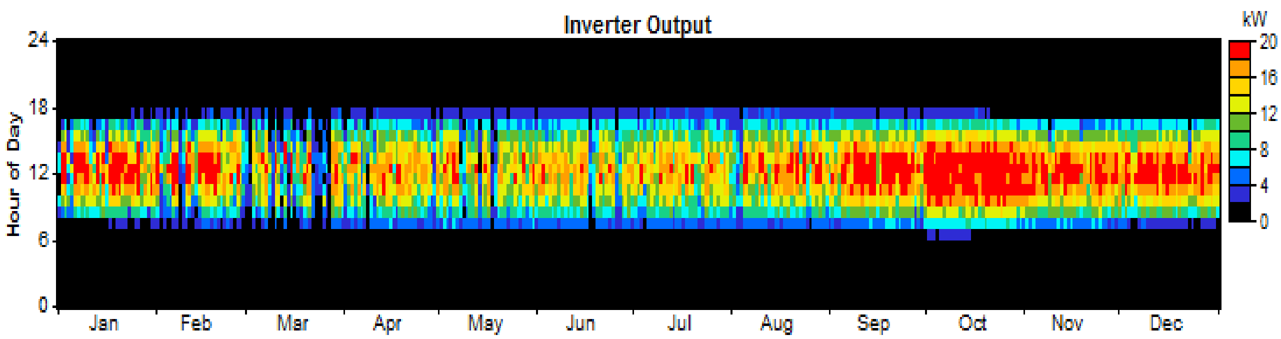

Fig.10. Inverter output

EMISSION FROM THE SYSTEM

The table below illustrates the system's emission level. As one of the system's noble features, the program suggests using hybrid Solar PV and Grid energy instead of traditional system, with the model able to reduce 11,063 kg of CO_2, 48 kg of SO_x, and 23.5 kg of NO_x each year. The technology demonstrates an ideal combination for reducing a significant amount of carbon footprint and other important pollutants that contribute to global warming.

Table 4.1 Emission from the system

Pollution	Emissions (kg/yr)
CO2	-11,063
CO	0
Unburned hydrocarbons	0
Particulate matter	0
SOx	-48
NOx	-23.5

HOURLY ENERGY BALANCE OF THE PROPOSED SYSTEM

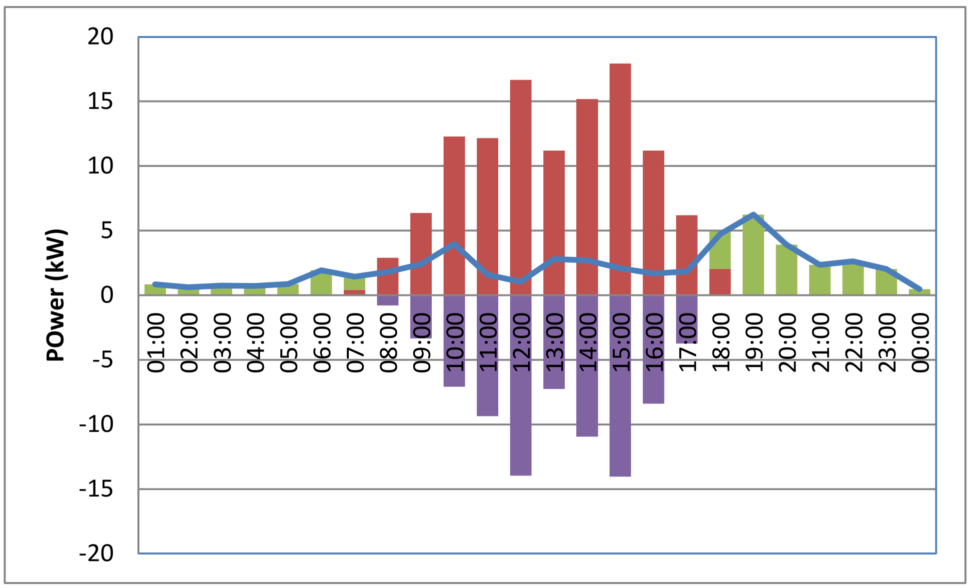

Fig.11. Hourly energy balance

The above picture depicts an illustration of the hourly grid interaction result for September 29 in order to analyze the suggested models energy equilibrium. Obviously, the available power yield is employed first to cover the systems power need. When the energy balance from the Solar PV and burden does not synchronize, the grid-network association comes into picture. PV power generation is shown in red bar, while load addresses is in blue lines. Surplus energy is shown in yellow bar and the energy taken from the grid is shown in grey bar. When there is an surplus of energy, it is provided to the grid, and in the converse case, the energy is taken back. The grid association exercises are controlled using a net meter with a predetermined value.

SENSITIVITY ANALYSIS

The sensitivity analysis protects against market volatility and cost unpredictability. In recent years, the cost reduction and technological advancement of renewable energy sources has been encouraging in the Indian setting. As a result, the analysis assumes that the system cost would likely drop in the future. To replicate dropping costs for long-term analysis, the calculation includes up to a 25% reduction in PV and a 30% reduction in Inverter prices. However, the cost of power taken and sold remains constant over a lengthy period of time, and such values are not incorporated in these analyses to avoid complexity. When the cost of PV and inverters was decreased by their maximum value, the cost of electricity was dramatically reduced.

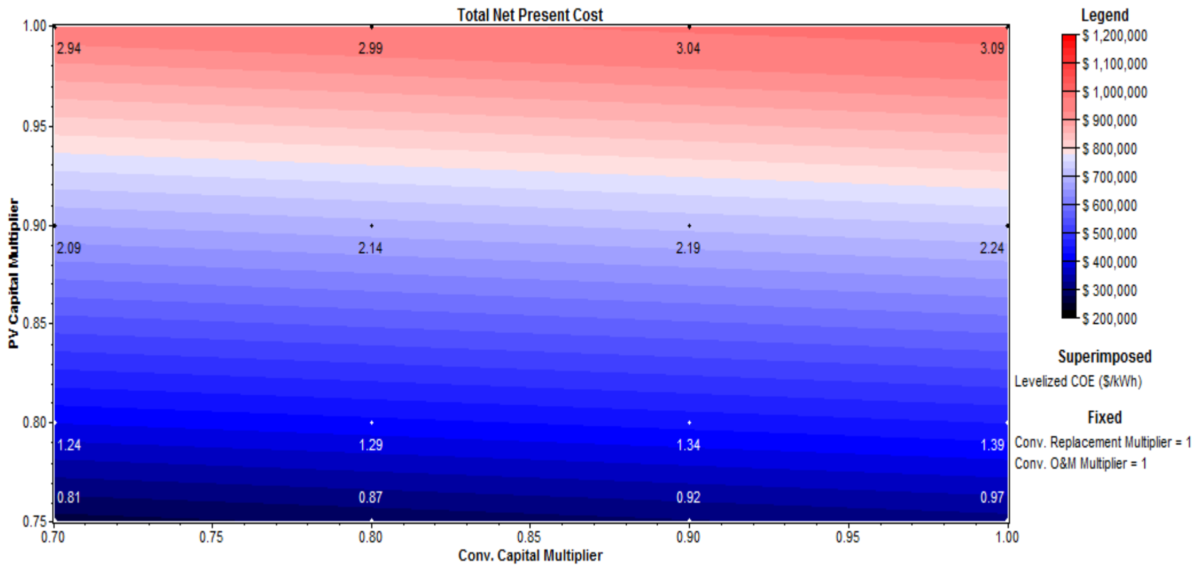

Fig.12 Surface plot of the model

GENERATION MIX

The graphic below depicts the generation mix for various months. The output of solar PV is changeable and weather dependant, whereas grid electricity is not affected by the weather. The model's total annual power generation is 60,537 kWh. The PV power output is shown by the blue bar, which accounts for 47,837 kWh, or 79% of the system's load needs, with the remaining energy coming from the grid, which accounts for just 21% of the system. It is worth noting that the total energy collected from the grid is less than the total energy sold via and to the grid.

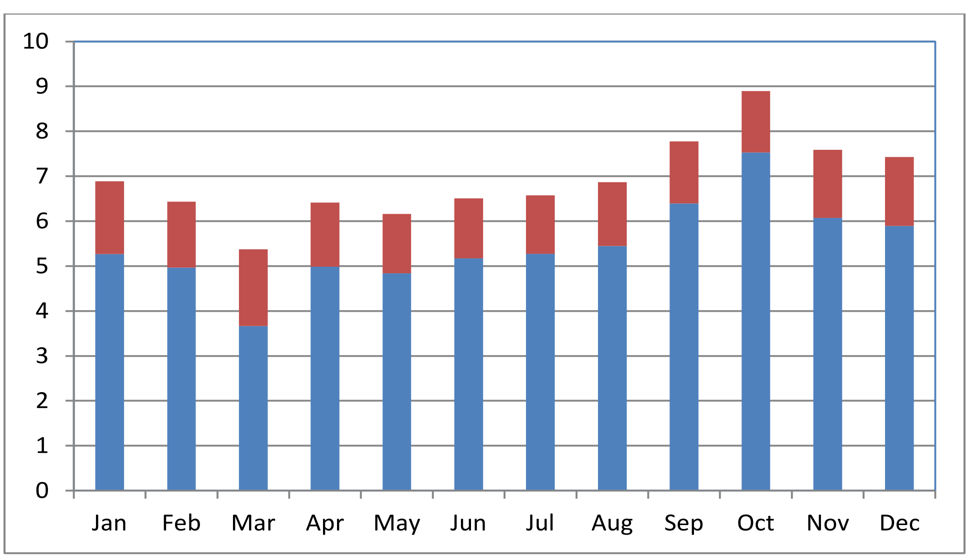

Fig.13. Generation Mix the model

ECONOMIC ANALYSIS

Table 4.2 Optimization result of PV-grid integrated system

PV (kW)	Converter (kW)	Grid (kW)	Initial capital (INR)	Operating cost ($/yr)	Total NPC	COE (INR/ kWh)	Renewable fraction	Capacity shortage
25	20	1000	$ 2,918,000	-149,937	$ 1,001,307	3.092	0.79	0.00
25	25	1000	$ 2,960,000	-146,751	$ 1,084,033	3.348	0.79	0.00
25	15	1000	$ 2,876,000	-125,567	$ 1,270,829	3.925	0.79	0.00
20	15	1000	$ 2,326,000	-68,868	$ 1,445,640	4.464	0.74	0.00
20	20	1000	$ 2,368,000	-67,682	$ 1,502,794	4.641	0.74	0.00
20	25	1000	$ 2,410,000	-62,367	$ 1,612,747	4.980	0.74	0.00
15	15	1000	$ 1,776,000	11,386	$ 1,921,555	5.934	0.68	0.00
15	10	1000	$ 1,734,000	15,793	$ 1,935,890	5.978	0.68	0.00
20	10	1000	$ 2,284,000	-25,502	$ 1,957,997	6.047	0.74	0.00
15	20	1000	$ 1,818,000	16,702	$ 2,031,508	6.274	0.68	0.00

The above table shows the general specification of the model which is produced in the HOMER programming. The initial 3 section shows symbol , next three segment demonstrate number or size of every part, the following six segment shows key reenactment results, for example, Initial capital expense of the framework, Operating expense, Net present expense, Levelized cost of COE, Renewable portion and Capacity lack. The ideal design is the one having least NPC which contains 1000kW of grid, 25 kWP PV, 20 kW converter. The COE is observed to be 3.092/kWh and 79% renewable penetration. There is an opportunity of income of INR 99,626 yearly.

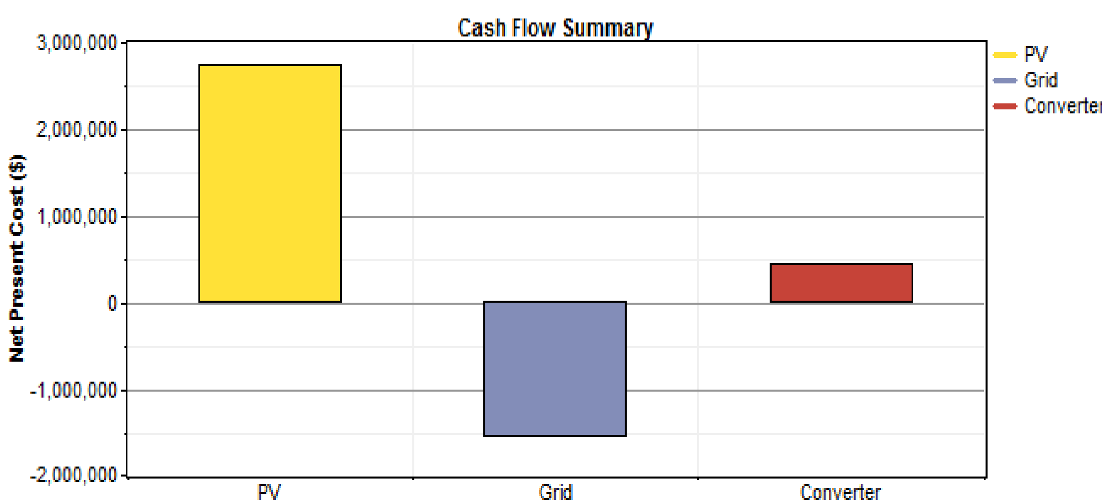

Fig.14. Cash flow outline of the project

To decide NPC, an financial insight investigation is carried out which displayed in above fig. it uncovers the capital expenses which dependent on the parts chose on the scheme. PV shares the most extreme capital expense. The converter shares the least as far as the current framework is considered.

CONCLUSION

The feasibility of a PV-Grid coordinated architecture is examined in this paper. The incorporation of grid boosts the system's dependability. The levilised energy cost is 3.092 INR/kWh, with a capital outlay of INR 29,18,000. The system is also capable of generating INR 1,71,545 per year as income. The plan not only increases supply dependability but also addresses environmental issues and aids in the reduction of significant amounts of pollution. With these promising results, the system is recommended.

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