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RESEARCH ARTICLE

Techno-Economic Feasibility of Hybrid Energy Systems Installation in Pakistan

OSAMAH KHALED, MUHAMMAD ZAHID, TAUSIF ZAHID, AND TEHSEEN ILAHI
Department of Electrical Engineering, Riphah International University, Lahore 54000, Pakistan
Corresponding author: Osamah Khaled (osamataiar1@gmail.com)

ABSTRACT This research work proposed an optimal hybrid microgrid design for Riphah International University (RIU), Lahore, Pakistan, that ensures a continuous and affordable energy supply by harnessing reliable energy sources. The design factors include the various considerations such as energy resource availability, environmental sustainability, and financial viability. The proposed hybrid renewable energy system integrates the national grid, solar photovoltaic (PV) technology, a battery bank, and a converter to fulfill the energy requirements of RIU. In order to develop the most efficient design, various factors are taken into account, including electrical load, solar irradiation, ambient temperature on campus, lifespan and efficiency of PV modules, degradation factor, cost considerations, battery longevity, energy prices from the national grid, occurrences of load shedding, and the environmental impact in terms of toxic emissions. The net present cost (NPC) factor is also considered to make the design more cost effective. The simulations conducted using HOMER Pro software yielded 932 possible solutions, among which the proposed hybrid microgrid design emerged as the most viable with an NPC of $0.483 million and 99.3% renewable energy utilization. The worst design, which utilized a national grid and diesel generator, resulted in an NPC of $1.89 million with 0% renewable energy integration. The proposed hybrid microgrid design among 932 models established by HOMER Pro software using PV connected to a national grid, and a storage system represents the most optimal solution for RIU Lahore Campus by considering all the necessary factors and requirements.

INDEX TERMS Photovoltaic, hybrid microgrid system, HOMER pro software, feasibility analysis, cost of energy (COE), renewable energy fraction, net present cost (NPC).

I. INTRODUCTION

Dependence on the consumption of fossil fuels as an energy source causes economic and environmental problems such as the high cost of electricity bills, global warming, and pollution. Diesel and petroleum generators are used in systems like off-grid and on-grid to provide a reliable source of energy. Fossil fuel usage has increased as a result in Pakistan; hence it is the main source of electricity, which causes noticeable power outages due to increased demand for loads, especially in summer. To overcome this problem, we can add more sources of energy to the existing power network, therefore renewable energy specifically solar energy represents an economic and technical solution to this problem. This effort seeks to schedule various systems for energy configurations that need examination while also achieving the best possible financial and technological feasibility analysis for hybrid energy systems. To build Pakistan's energy sector, it must do its utmost to improve the efficiency of the energy system while following environmental and energy sustainability. To increase the quality of the power for a specific load factor and to achieve optimal power consumption for the user, this study investigation will show the techno-economic viability of hybrid renewable energy. The main objective is to assess and simulate an effective techno-economic ON/OFF hybrid solar PV energy system that will maximize RES fraction and minimize economic factors such as net present cost (NPC), cost of energy (COE), and operating cost (OC). As well as

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reducing the greenhouse gas (GHG) emissions to partially or completely address Pakistan's present energy supply shortage. Fossil fuels are the largest contributors to greenhouse gas emissions and climate change, and renewable energy sources are a cost-effective, sustainable, and viable alternative. The use of solar energy, in particular, has great potential for producing electricity globally. However, access to fundamental energy services remains a challenge in Pakistan, where a significant portion of the population lacks electricity and relies on fuelwood and biomasses for energy. Microgrids, which can function independently or in conjunction with a utility grid, offer a resilient and stable alternative to traditional energy grids, and renewable energy-based designs can maximize performance by combining multiple sources of energy with a storage system. This research aims to evaluate the integration of flexible alternatives and renewable technologies into national energy systems, focusing on Pakistan's energy system as a case study. The study aims to identify the best hybrid microgrid configuration that uses reliable renewable energy sources to deliver energy to Riphah International Lahore, Pakistan, without interruption and at the lowest cost. The research highlights the need to reduce reliance on traditional energy sources and decrease carbon emissions by generating electricity from renewable energy sources. The study uses Homer software to simulate the hybrid microgrid design under different load demands, considering energy storage, technical and economic performance, and environmental impacts. The study's findings may also apply to other energy systems in nations with comparable features and contribute to renewable energy analysis knowledge and comprehension.

This literature review provides an overview of past research on microgrid principles, power management of microgrids, distributed generation, microgrid power electronics, microgrid stability, and mathematical modeling of parts. Additionally, it encompasses the examination of renewable energy resources and the advancements made in the corresponding sector within the country under study. The focus of this research is on the economic feasibility of hybrid energy, specifically solar energy (photovoltaic), for a commercial-scale system at an educational facility (RIU University). The study suggests that renewable energy sources must be used efficiently to meet rising energy demands and reduce overall energy consumption. The results of the scientific studies showed that using renewable energy as a significant source of energy can reduce overall energy consumption and may provide a workable alternative for reducing the building's energy demand [1], [2]. There is growing concern that the world is approaching a point where its energy resources will be depleted due to the rapid consumption of fossil fuels. This poses a particular challenge for developing nations whose economies heavily rely on these energy sources. Given the present situation, it becomes imperative to optimize the effectiveness of renewable energy resources to address the ever-increasing need for energy. Furthermore, the current unfavorable global economic and political climate, coupled with a rising interest in the development and implementation of renewable energy technologies, underscores the need for nations to become more self-reliant in their energy supplies. The significance of generating power from renewable sources is heightened by their ability to produce electricity with minimal carbon dioxide (CO2) and greenhouse gas (GHG) emissions, while also minimizing pollution of water and soil. Solar, wind, hydro, and biomass are the four main categories of renewable energy sources, and they all have a significant potential to address upcoming energy concerns. Solar photovoltaic technology was among the pioneering renewable energy solutions adopted worldwide to provide electricity for essential needs, especially in remote and underserved areas. This study discusses a survey of the research on the techno-economic feasibility of solar photovoltaic power generation. One of the key engines behind global industrial progress and economic expansion is energy. Fossil, nuclear, and renewable energies make up the three main categories of energy resources. Governments must overcome obstacles such as growing fossil fuel prices, increased energy consumption, unpredictability in the supply of energy resources (particularly natural gas and oil) due to geopolitical issues, and environmental consequences like global warming. The review also discusses the potential of solar photovoltaic technology to supply electricity in distant places and address energy concerns, especially given the depletion of fossil fuel reserves [3]. The primary draw of renewable energies is sustainable development goals and energy security [4], [5]. In general, the review of existing literature underscores the significance of renewable energy sources in promoting sustainable development, curbing greenhouse gas emissions, and addressing the adverse environmental effects associated with energy generation. Several researchers, including Yousif, Sahal, and Sandro, have undertaken feasibility studies that highlight the significance of renewable energy, particularly solar-wind hybrid systems, in the Al-Tafila district of Jordan [6]. In [7] a study conducted by Yoo, the correlation between electricity consumption and economic growth was examined in four ASEAN countries spanning the period from 1971 to 2002. The findings revealed a unidirectional causal relationship where economic growth influences electricity consumption in Indonesia and Thailand. This suggests that energy conservation measures can be implemented in these countries without adversely affecting their economies. Goel and Ali conducted an analysis of demand, capital costs, and energy costs associated with different types of resources [8]. Shafiullah et al. investigated various configurations of PV-Wind hybrid systems for a village in Algeria, while Chedid assessed the operational costs of a WIND/PV/DIESEL system using a custom-built programmer [9]. Masanga and Samusodza proposed a hybrid system for an Indian village that achieved the lowest electricity cost, providing a 24-hour power supply at a rate of \$0.14 per kilowatt-hour [10]. Several studies focused on optimizing hybrid PV/Wind systems, primarily using HOMER software [11], [12]. However, most studies did not consider externalities when calculating the LCOE, which is essential to defend the viability of their designs.

In [13], the authors proposed an optimized microgrid design for MUST university, Azad Jammu, and Kashmir AJK, Pakistan uses reliable energy resources at the inexpensive price. Key design factors include energy resource accessibility, environmental compatibility, and financial viability. The MUST site is equipped with readily available resources such as the solar energy, storage systems, a generator (diesel), and other essential infrastructure such as converters which designed for a remote place. In this research, trackers enable power plants to produce up to 20% more electricity annually. With this technology, the range of output adjustments allows the quantity of production to fluctuate from a 44% rise in the summer to a 15% decrease in the winter. The design and features of the power plant's machinery have a significant impact on energy production. As a result, there are only a few monitoring PV power plants in various Iranian regions. Additionally, the lifespan of a PV power plant is constrained (maximum 3 years) [14]. The research utilized a hybrid system, which showed great promise in significantly decreasing the heating and cooling loads of a DX/HP unit. When compared to conventional stand-alone rooftop PV and BIPV/T systems, the suggested hybrid system outperformed them with superior results. The quantity of hot water storage required was primarily influenced by the heating load, while the payback time (PBT) was significantly affected by inflation. Significantly, the performance metrics exhibited fluctuations of 80.1% and 41.2% correspondingly, as the cooling load was modified between 80% to 120% of the reference condition. Due to the cheap cost of electricity in the household sector, investment in this type of equipment is unpreferable [15]. Global photovoltaic system prices are falling, which would enable the government to increase investment. These PV systems can significantly reduce greenhouse gas emissions by increasing the reliability of power generation and compensating for power demands. Upon analysis of the generated map depicting the potential for renewable energy, a total of seven distinct zones have been identified in [16].

In the context of renewable energy systems, Chong Li and his team [17] carried out a techno-economic analysis of a hybrid wind/diesel/battery setup in a small residential area located in China. To conduct their assessment, they employed the HOMER software and examined three types of batteries: lead-acid (Lacid), lithium-ion (Li-ion), and flow batteries. Similarly, Murugaperumal and his colleagues [18] also utilized the HOMER software to conduct a study on rural electrification. Their research focused on assessing the most efficient arrangement and techno-economic feasibility of a hybrid PV/wind/biomass/battery system for the electrification of rural areas. Another study focused on the economic and environmental viability of a hybrid PV/wind/biogas/fuel cell system, leveraging HOMER to identify the most suitable configuration to meet the electricity needs of an Iranian village [19]. Odou et al. also utilized HOMER to investigate the impact of dispatch techniques, generator, and battery technology choices on the COE and the NPC for sizing Hybrid Renewable Energy Systems (HRESs). While the above-mentioned studies shared a common objective of sizing HRESs, other research has delved into the multi-objective optimization of these systems. For instance, Fodhil et al. employed a diesel/battery HRES based on Particle Swarm Optimization (PSO) and the ε-constraint approach to simultaneously decrease the total system cost, unmet load, and CO2 emissions in an off-grid PV system. Similarly, Ghorbani et al. [20] optimized a hybrid wind, PV, and battery system using a Hybrid Genetic Algorithm with Particle Swarm Optimization (GA-PSO) and Multi-Objective PSO (MOPSO) to reduce the NPC and Levelized Production Cost (LPC) while meeting the load requirements. The design in [1] looked into ways to lower the amount of electricity needed by the engineering faculty at Mu'tah University. One strategy to lower energy consumption and power generation is through making efficient and effective use of the resources already at hand. Photovoltaic systems connected to the grid are seen to be the most effective way to save money. Consequently, the Faculty of Engineering suggested the establishment of a 56.7 kW solar photovoltaic power plant that would be connected to the grid. This initiative aims to meet the electricity demands by harnessing the potential of solar photovoltaic systems, which have proven to be a sustainable and environmentally friendly means of generating electricity. Similarly [21] addressed this topic for the Balochistan province of Pakistan by evaluating the potential and viability of solar PV for rural electricity in the region. The province of Balochistan appears to have the highest sun irradiance value worldwide, according to the statistics. Additionally, calculating the best tilt angles for a given region can considerably boost solar energy output. Based on an economic feasibility analysis conducted on solar PV systems, the rate of energy generated by these systems was Rs 7.98 per kWh, which is considerably lower compared to the cost of traditional electricity at around Rs 20.79 per kWh. This study takes into account building energy efficiency and climate diversity, in contrast to previous research, to investigate the influence of these factors on the optimization of HRES size. The optimal configuration for Adrar and Tindouf is discovered to be photovoltaic/wind/diesel/battery. The more advanced option, situated in the Biskra and Tamanrasset microgrid, features a COE amounting to 0.21 dollars per kilowatt-hour (kWh) and utilizes a PV-Battery system that exclusively relies on 100 percent renewable energy sources. This option incorporates a seamless integration of distributed energy generation resources, energy storage banks, and various renewable energy sources. The microgrid can either function as a stand-alone energy resource or it can be connected to the grid. The choice is based on the resources that are accessible at the targeted location. The independent microgrid is the best option for all energy needs in distant places. In contrast, the grid-connected microgrid is better suited for metropolitan settings. The main benefit of integration is that energy production would also be done by the customer [22]. In comparison to the traditional energy setup, the microgrid is more dependable, adaptable, and promising [23]. There are now three major kinds of microgrids in use: The first design features AC sources interconnected to a single bus, efficiently supplying power to AC loads through transformers or AC/AC converters. In contrast, the second design constitutes a DC microgrid with DC energy generation sources connected to the DC bus, providing energy to DC loads through DC/DC converters. Lastly, the hybrid microgrid (HBMG) combines both DC and AC microgrids, utilizing AC and DC bus bars. AC/DC and DC/AC converters facilitate energy transfer from both sources to the DC and AC loads, connecting them to their respective bus bars [24]. Microgrids have been extensively studied, and their advantages, challenges, and opportunities are well-documented in the literatures [25] and [26].

Hybrid microgrid models were developed using HOMER software to assess the techno-economic feasibility of increasing electrical energy output through renewable energy resources in the Maldives, South Korea, Australia (specifically, Busan), and Bangladesh [27], [28]. In addition, researchers evaluated the practicality of off-grid solar PV systems and hybrid PV/WT systems in Nice, France, and Nicosia, Cyprus. [29]. Authors in [30] used HOMER Pro to observe the dependability and anticipated cost for a microgrid built on PV, WT, Fuel cells, and BESS. The researcher's focus is now on the viability of the PV/WT/DG system due to the growth in fuel prices and energy consumption. In the present industrial period, there has been a considerable decline in CO2, which is concerning for the entire world [31].

In [32] the study conducted techno-economic analyses and environmental comparisons of various hybrid systems to meet the electricity needs of the Köyceğiz district of Mugla independently of the grid. The hybrid energy system consisted of a Solar Panel-Wind Turbine and Battery, with an average daily electricity consumption of 150,000 kWh.

Design of a hybrid energy system with solar-wind-diesel generator-battery components had been designed in [33] to meet the electricity demand of a closed prison. Simulations are conducted with 5 different battery scenarios, and the vanadium redox battery system was shown the most optimum in terms of high renewable energy ratio and low energy cost.

Authors in [34] showcases the optimization and comparative analysis of hybrid and off-grid charging stations in Turkey using the HOMER program, aiming to support the transition to renewable energy and reduce carbon emissions. In [35] study focused on developing a methodology for designing hybrid storage micro-grids with renewables and hydrogen, aiming for seasonal storage. An optimization code is presented, applied to a case study micro-grid near Rome, resulting in an optimal design with an electrolyzer, fuel cell, and battery capacity, enabling efficient hydrogen production. Where [36] proposed a solar-wind-diesel hybrid power system for remote ATM machines, aiming to address energy crisis issues. Authors in [37] optimally designed a hybrid PV/biogas/diesel/battery sustainable system for a village in Xuzhou, China. While these studies offer valuable insights into hybrid renewable energy systems, it's important to acknowledge their limitations.

Based on prior academic research, the most viable approach involves embracing hybrid renewable energy microgrids to effectively meet energy demands. Moreover, to adhere to established industrial practices, the HOMER software emerges as a widely utilized optimization tool for simulating and enhancing the performance of these hybrid renewable energy microgrids. It is essential to recognize that the availability of various renewable energy sources varies considerably depending on the location. To lessen reliance on diesel generators and traditional sources, an integrated and hybrid system is required. The sustainability and efficiency of a hybrid system would be increased by using multiple renewable energy sources. Given the environmental advantages of renewable energy sources, the principal objective of this investigation was to propose a comprehensive strategy that effectively reconciles the realms of economy, environment, and energy. The present study employed diverse setups encompassing a hybrid system functioning independently from the power grid, supplemented by a diesel-driven generation system for contingency purposes, a PV energy system, and a storage-oriented generator. Finally, a hybrid system (ON/OFF Grid) was used to discover the best configuration for a university campus. It consists of PV-based energy, a storage system, generators, and a grid. The simulation outcomes revealed that the COE and NPC of the proposed configuration exhibited a significant reduction compared to alternative energy sources. This finding underscores the capacity of the proposed configuration to generate the required power at a reasonable expense. Consequently, if an unconventional location is chosen, the PV hybrid arrangement emerges as the most feasible configuration. In order for a microgrid to be deemed suitable, it must satisfy specific criteria within the realm of economic viability, reliability, and environmental sustainability. Ensuring uninterrupted power supply during periods of low energy production necessitates careful consideration of battery backup selection, which assumes a critical role in microgrid design. This is especially important given the unpredictability of weather conditions and the unreliability of the grid. With a battery backup, the microgrid can maintain a steady supply of electricity. Moreover, the microgrid can enable the use of various energy resources, and the energy management system can determine the most appropriate combination of resources based on factors such as cost, reliability, and power quality.

To meet the electricity demand of RI university, a study has been planned to develop a model for a hybrid renewable energy microgrid. This study aims to make three key contributions

1) A framework for optimizing a hybrid microgrid has been proposed for the RIU Lahore Campu that takes into account the main aspects of sustainable development goals such as economically, dependability, and sustainability.
2) Benchmarks have been identified for each of these goals. For economically, the benchmarks are lower net present value, capital investment, and costs of energy. For dependability, the benchmarks are uninterrupted power supply, reduced energy shortages, and assured power quality. For sustainability, the benchmarks are a higher percentage of renewable energy usage and reduced emissions.
3) The research study entails the development and analysis of a hybrid renewable energy microgrid, consisting of PV, and battery backup components, for the purpose of achieving sustainable energy generation at the Riphah International University, Pakistan. The analysis and modeling of the microgrid incorporate local weather conditions and the optimization process involves the selection of an optimal configuration that aligns with the sustainable development goals.

According to the best of the authors knowledge, this kind of study has been not implemented yet for the RIU Lahore Campus. This endeavor represents a significant contribution to the research in the field of renewable energy and its potential applications in achieving sustainable development objectives. By taking into account researched benchmarks as constraints, the hybrid renewable energy microgrid is optimized to select the most practical configuration in the context of the sustainable development goals. This research study utilized HOMER Pro's simulation to perform the optimization and sensitivity analysis with grid-connected operational modes along with the integration of renewable energy sources.

A. HOMER SOFTWARE

The HOMER-Pro software is a potent instrument to create an ideal hybrid design to assure continuous and affordable electricity under particular circumstances [38]. Moreover, evaluates crucial variables for both grid-connected and off-grid models in order to determine the most effective hybrid configuration. By exploring various combinations of available resources, HOMER-Pro delivers precise and fair findings. HOMER-Pro features meteorological statistics from National Aeronautics and Space Administration (NASA) to assess the ability of renewable resources at any site. The program functions in three stages, with the first involving the input of project details such as site-specific location, resource availability, load profiles, and system components. The second stage involves simulation and optimization with specific parameters of interest, and the third stage displays the outcome and provides comprehensive information on economic metrics, performance, and sizing of system.

Software tools for microgrid optimization such as HOMER, HYBRID2, HOGA, TRNSYS, HYDROGEMS, HYBRIDS, INSEL, ARES, RAPSIM, SOMES, and SOLSIM are some of the most often utilized. Depending on the situation, HOMER can simulate tens of thousands of different solutions. One approach involves creating a representation of the desired system by estimating the expenses associated with installation, operation, replacement, and maintenance (O&M), fuel, and interest rates. During the optimization phase, the configuration generates a ranked list of configuration outcomes based on the Total Net Present Cost after the simulation step (TNPC). From the lowest to the greatest TNPC, HOMER investigates the many forms of system configurations. On the other hand, the user's selection of the sensitivity variable affects the system setup based on TNPC. In the sensitivity phase, which is an optional step, sensitivity factors like wind speed, solar radiation, fuel prices, and so forth are presented to evaluate how the ideal system changes when these variables [39], [40]. Many factors are taken into account by HOMER, such as technological viability, climate, load consumption, and economic parameter analysis. HOMER tool requires the cooperation of stakeholders including proponents of renewable energy, power engineers, utility operators, and financiers.

II. METHODOLOGY

This section outlines the method employed, including data modeling, component descriptions, site resources, and economic characteristics. A brief introduction to HOMER software is already provided in the introduction part. The main objective of this study is to suggest a microgrid

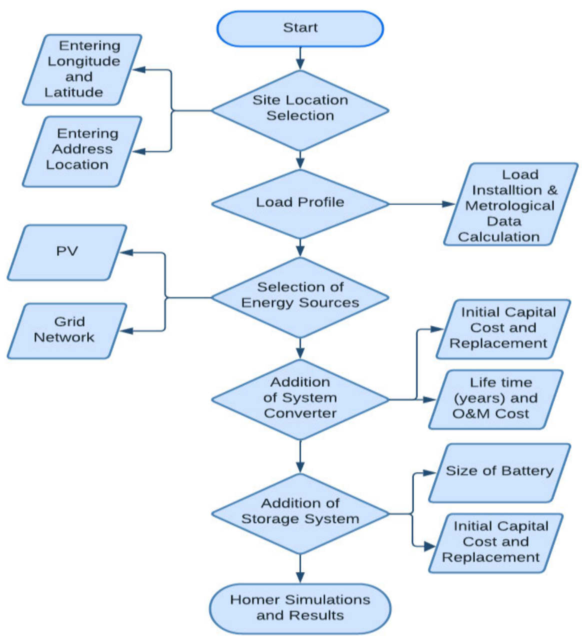

FIGURE 1. Methodology's flowchart.

TABLE 1. Installed load of the selected site for RIU, Lahore campus.

Classification of Load	APLIANCES	Quantity	Wattage	Total Energy (kW)
Lights Equipment	Light Bulb	112	20	2.24
	Light Spot	22	15	0.33
	Light Tube	176	20	3.52
	Light (1 x 1)	410	20	8.2
	Light (2 x 2)	117	48	5.616
	Table Lamp	1	20	0.02
	Operation theater	8	60	0.48
	Light Pole	20	80	1.6
Fan equipment	Exhaust Fan	25	100	2.5
	Fan/Ceiling	274	100	27.4
	Ceiling (2 x 2)	9	55	0.495
	Fan /Pedestal	1	75	0.075
	Fan / Bracket	45	60	2.7
Total Wattage of Load Type 1(L1)				55.176
Printers	Printers	50	24	1.2
	Photocopy Machines	250	2	0.5
	Desktop System	250	121	30.25
	Internet AP	20	65	1.3
Computer System	UPS	380	3	1.14
	LED TV	100	1	0.1
	CCTV Cameras	20	96	1.92
Other Electric Equipment	Fridge	500	7	3.5
	Water Dispenser	80	12	0.96
	Blowers	360	1	2
	Server Racks	500	4	3.2
	Underground	1600	2	0.1
	Microscope	100	1	0.36
Total Wattage of Load Type 2 (L2)				39.91
Air Conditions	A.C (1 Ton)	1500	1	1.5
	A.C (1.5 Ton)	1900	62	117.8
	A.C (2 Tons)	2500	2	5
	A.C (4 Tons)	3000	26	78
Total Wattage in of Load Type 3 L3				208.92
Total Load kW (L1+L2+L3) for RIU, Lahore Campus				**304.006**

configuration suitable for Riphah International University's (RIU) campus in Lahore. The microgrid aims to ensure a consistent and affordable power supply. However, estimating the future operational expenses of microgrids for the next 25 years poses a challenge due to several factors, including volatile fuel costs, grid disruptions, solar panel degradation, and shifts in energy consumption trends. Therefore, to construct an optimal microgrid power system that can achieve the desired outcome within the next 25 years, it is essential to consider these factors. HOMER software is a reliable tool that can simulate a microgrid system, taking into account all the relevant variables and circumstances of the RIU campus. The research methodology's flowchart is displayed in Figure 1. The complete process of the optimization with HOMER Pro software is explained in the following sections.

A. LOCATION SELECTION

For the proposed research work, the Riphah International University, situated in Lahore was considered. This campus is positioned in a flat geographical area, making it preferable to select an on-grid site. The latitude and longitude coordinates for Riphah International University, Lahore campus are approximately 31.5667° N latitude and 74.3587° E longitude.

B. DATA CALCULATIONS AND LOAD PROFILE

The RIU Lahore Campus load is divided into three different load categories (Load Type 1, Load Type 2, Load Type 3).

Accurately calculating the load was a crucial aspect of our research work. The load type 1 and load type 2 comprise lighting equipment, fan equipment, multimedia, printers, computer systems, and other electrical equipment that are used throughout the year (annual load). Conversely, load type 3 includes air conditioning, water dispensers, blowers, and underground equipment (seasonal load). To design our system, the calculations are performed based on the peak demand of the RIU, Lahore campus site, and table 1 provides a detailed breakdown of the installed load.

Data on solar and climatic conditions globally were provided by the National Aeronautics and Space Administration (NASA) to support and further research on renewable energy sources. It For the chosen site, NASA reported that solar radiation varies from a minimum of 3.24 kWh/m^2 per day in December to a maximum of 7.34 kWh/m^2 per day in May, which is a hot and extended month. The Lahore campus site of RIU, with an average daily solar radiation of 5.32 KWh/m^2, offers an excellent opportunity for energy generation. Based on the site selection data, the clearing index and sun illumination of the location is mapped as shown in Figure 2. It can be seen from figure 2 that, the term global horizontal irradiance (GHI) represents the total number of solar radiation incidents on a horizontal surface. The data is collected for 22 years to calculate the average monthly global horizontal irradiance. The clearness index, which ranges from 0 to 1, indicates the clarity of the air. The index has a high value when the sky is clear and sunny, and a low value when the sky is cloudy. Overall analysis confirms that the RIU, Lahore campus site has an excellent potential for solar energy production.

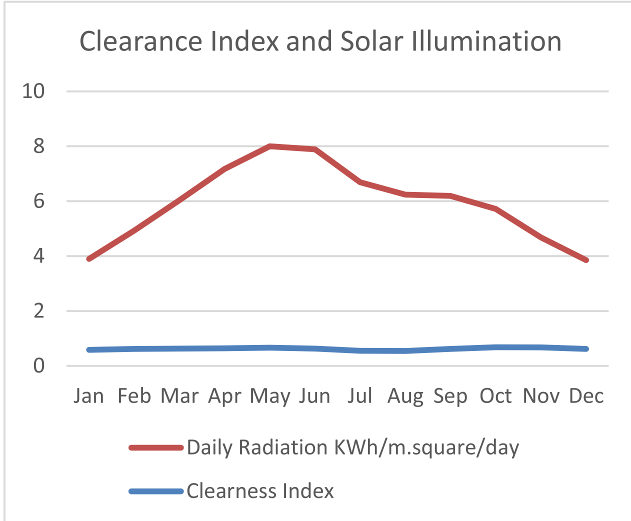

FIGURE 2. Monthly clearness index and solar illumination of the site.

As the temperature of a PV cell increase, there is a likelihood of a decline in the performance of the PV module. To maintain the efficiency of a PV module, it is important to control the PV cell temperature at high temperatures by implementing cooling measures. PV module efficiency losses are quantified using the temperature coefficient, which is typically set by solar panel manufacturers for temperatures over 25°C. However, temperature data collected for Lahore indicates that efficiency losses during solar energy generation are negligible, as depicted in Figure 3. Monthly temperature data spanning a 30-year period from January 1984 to December 2013 was collected for the analysis. The yearly average temperature was found to be 16.09°C, with a daily minimum temperature of 7.49°C in January and a daily high temperature of 37.35°C in June. It can be seen from Figure 3 that the temperature data was higher from May to October and lower from November to March.

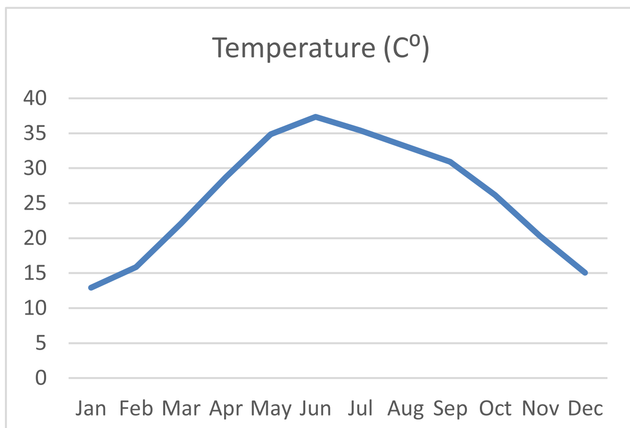

FIGURE 3. Monthly average temperature data of the site.

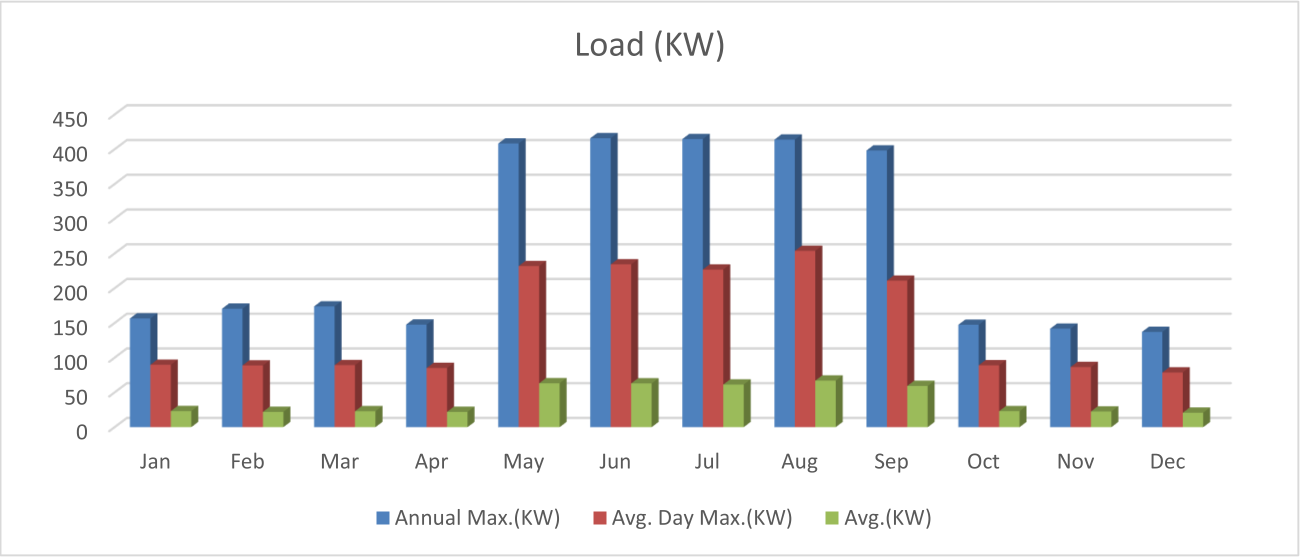

FIGURE 4. **One-year site load profile.**

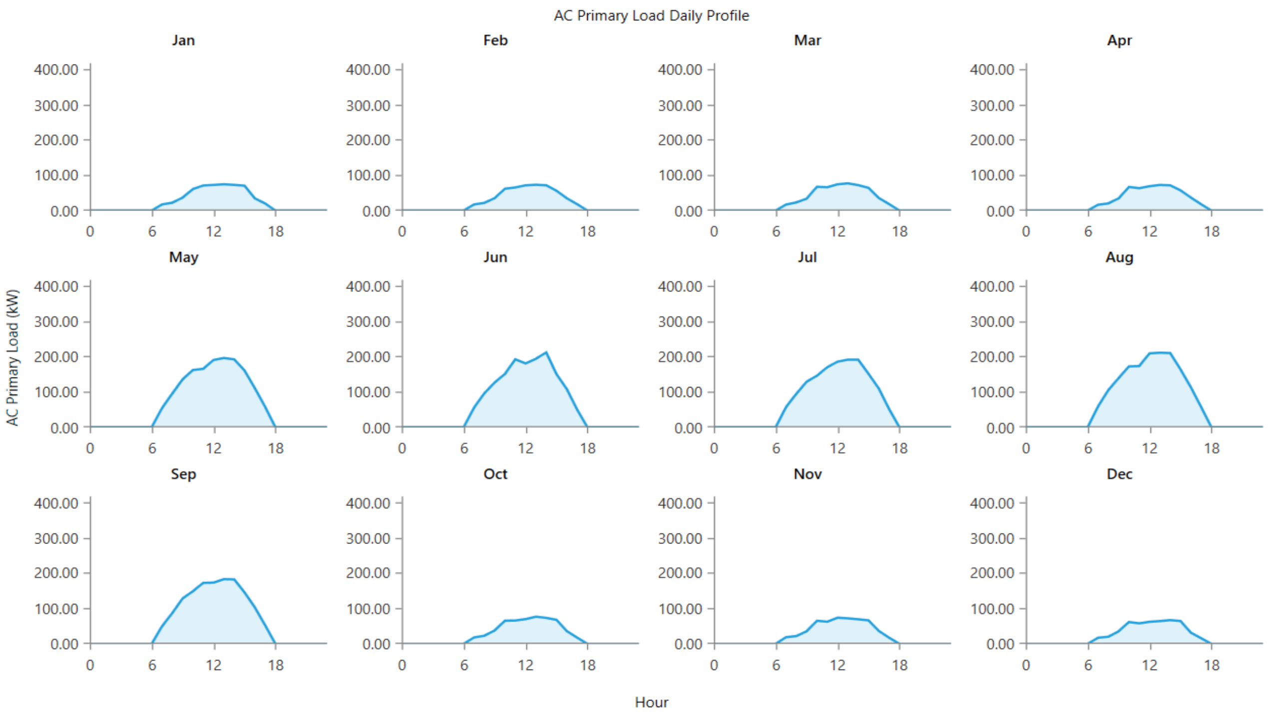

FIGURE 5. **Load profile for all day.**

C. ELECTRICAL LOAD

The load information entered in the HOMER for RIU Lahore. HOMER simulates daily, seasonal, and annual profiles to determine average and peak loads. The peak loads and average loads energy consumption for load types 1, 2, and 3 are presented. The monthly load profile for the RIU campus in Lahore is also displayed in Figure 4, which includes maximum daily and monthly energy consumption. Real-world data was used to create a microgrid and run simulations with current tariff charges and component costs. In the research, the load calculation played a significant role, and the system design was determined by the highest demand observed at the selected campus. Measuring on an hourly basis consistently for a year, the load on the RIU, Lahore campus was determined. Along with information on the average and maximum daily loads, the monthly load profile also shows the maximum monthly energy use. For a microgrid to be designed optimally, real-world data must be used as the basis for design.

The table makes it evident that campus departments use low energy throughout March and November. The increase in loads from fans throughout the summer season and electric heaters throughout the winter season is the cause of this peak usage. HOMER software shows the seasonal profile and daily load usage later on. The load functions during school hours and then completely stops. The university operates from Monday to Friday, with hours extending from 7:00 a.m. to 6:00 p.m. However, Saturday and Sunday are excluded from these operating hours. As a result, during the weekend, there is no activity or workload after 6:00 p.m., and there is absolutely no activity before 8:00 a.m. on Saturday and Sunday as shown in Figure 5.

D. HYBRID MICROGRID MODEL DESIGN

The design, development, and optimization of microgrids is implemented for the RIU Lahore campus. Figure 6 illustrates the existing model of all the accessible energy sources at RIU Lahore campus. The grid serves as the main energy source for the campus appliances, with the diesel generator serving as a backup. The optimal design is shown in Figure 7.

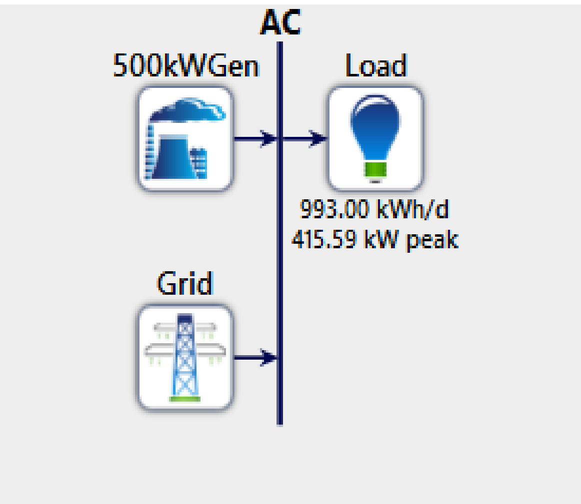

FIGURE 6. The available sources at university site (RIU).

E. ENERGY SOURCE

As a part of the study's objectives, the energy resources of the site were examined. Based on the analysis conducted earlier, the data indicates that the region holds significant potential for generating solar energy. Although other renewable resources like hydro, hydrokinetic, and biomass also show potential, this study specifically focuses on solar energy, along with storage systemization and the grid. To achieve this, the SG200M5 solar PV and 1 kWh storage were coupled to the DC bus as DC voltage sources, while the grid was linked to the AC bus as an AC voltage source. A bidirectional power converter was employed to manage the bidirectional flow of electrical energy by linking the DC and AC bus bars. Instead of the current load connected to the AC bus bar, a DC load

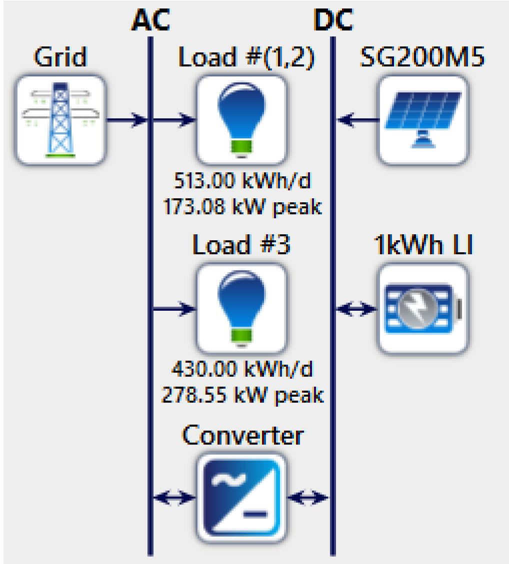

FIGURE 7. The proposed system for university site (RIU).

with a DC bus bar could be used. Table 2 provides details of the parameters for each element employed in both the initial and optimal designs of the microgrid. Additionally, the costs associated with acquiring components, gasoline expenses, grid tariff rates, and other relevant factors were calculated using the latest prices from the Pakistani market.

1) NATIONAL GRID

Grid connection is crucial as it allows the system to receive power and act as a backup in case of unpredictable solar resources or system failures. In addition, the surplus energy produced by the system can be sold to the grid. The Homer software's grid module is utilized to incorporate real-time rates, schedule rates, grid extensions, and reliability alternatives. Advanced grid modelling using simple rates was selected as the methodology for this study. The purchase price for grid energy is set at $0.22 per kWh, while the sell-back price is assumed to be $0/kWh.

2) SOLAR PHOTOVOLTAIC SYSTEM

One of the main goals of this study is to investigate the potential of PV technology as a renewable energy source for local electricity production. The integration of PV into buildings is gaining momentum globally, but the economic feasibility of installing solar PV systems in various types of buildings needs to be assessed prior to implementation. This assessment is closely linked to the characteristics of the load profiles, which can vary greatly between different building applications, such as commercial and residential buildings. The size of the energy storage component for a PV-integrated system is significantly influenced by how well the demand profile matches the solar radiation profile, which has a significant impact on the system's cost of energy. The output of a PV system is affected by temperature and solar illumination [39], [40], [41]. When designing a photovoltaic (PV)

TABLE 2. Description of the hybrid system parameters.

Components of System	Parameters	Unit Cost	Unit
Grid	Purchase Price	0.22	$/kWh
	Sellback Price	0.20	$/kWh
Solar Photovoltaic	Manufacturer Peimar lnc. (Brescia, Italy)		
	Panel Type Flat Plate		
	Rated Capacity	200	kW
	Efficiency	22.70	%
	Capital Cost	316	$/kW
	Replacement Cost	316	$/kW
	O&M	0.1	$/year
	Lifetime	30	years
Battery Bank	Manufacturer		
	Type Li-Ion		
	Nominal Capacity	1	kWh
	Capital Cost	101	$/battery
	Replacement Cost	101	$/battery
	O&M	0	$/year
	Initial State of charge	100	%
	Minimum state of charge	20	%
	Lifetime	15	Years
Power Converter	Manufacturer		
	Capital Cost	300	$/kW
	Replacement Cost	300	$/kW
	O&M	0	($/year)/year
	Lifetime	15	Years
	Efficiency (inverter input)	95	%
	Relative Capacity	100	%
	Efficiency (rectifier input)	95	%

system, several factors need to be taken into account, including the choice of materials, nominal output, derating factor, temperature, lighting conditions, and climate. The SG200M5 flat plate photovoltaic module was chosen for simulations in HOMER as part of this specific study.The module has a capital cost of $316, a replacement cost of $316, and an operation and maintenance cost of $0.1. It should be noted that the solar module chosen has a 30-year lifespan and is linked to the DC bus bar of the microgrid, functioning as a DC power source. Figure 8 illustrates the solar panel's peak power, average daily maximum power, and over all output power across the year.

3) BATTERY BANK

In the microgrid, a 1 KWh battery bank serves as a backup to provide power to the load at the lowest cost or in emergency situations. The simulation's capital and replacement costs ($101) for the battery bank were acquired from Rawalpindi, Pakistan, and the battery has a 15-year lifespan. To achieve optimal performance, the battery bank was set with charging and discharging thresholds at 100% and 20% respectively. It functioned as a DC source connected to the microgrid's DC bus bar. Figure 9 demonstrates the annual charging and discharging patterns of the battery.

4) POWER CONVERTOR

To ensure the bidirectional power flow in the microgrid, a 100 KW system converter was utilized. The converter operates as both an inverter for DC power supply and an AC rectifier. Its operational lifespan is 15 years, with a capacity of 100 KW and an initial capital cost of $300, as well as a replacement cost of $300. The converter is linked to both the AC and DC busbars of the microgrid, functioning with an impressive efficiency of 95%. The input and output power of the inverter are both shown in Figure 10.

F. EVALUATION STANDARDS FOR OPTIMIZATION

The research work involves five configurations, including design, simulation, and optimization, which require the establishment of assessment criteria before proceeding to the optimization stage. The assessment standards for this research include the LCOE, OC, CC, and the proportion of renewable energy used. Each of these criteria is extensively defined and elucidated based on their corresponding definitions in HOMER's index [42]. In this study, HOMER utilizes two key economic inputs for economic analysis: NPC and LCOE. These inputs are essential for determining the most optimal configurations. Hence, NPC is the most economically advantageous statistic in the HOMER tool for optimization among all factors [43]. However, the study will also discuss and evaluate the percentage of renewable fraction, startup costs, and operating costs.

1) NET PRESENT COST (NPC)

The project comprises of three stages: design, simulation, and optimization. Before proceeding to the optimization phase, it is crucial to establish the evaluation criteria. HOMER's index [42] specifies and elaborates on each criterion in this section. NPC is the total of a project's lifetime revenues and

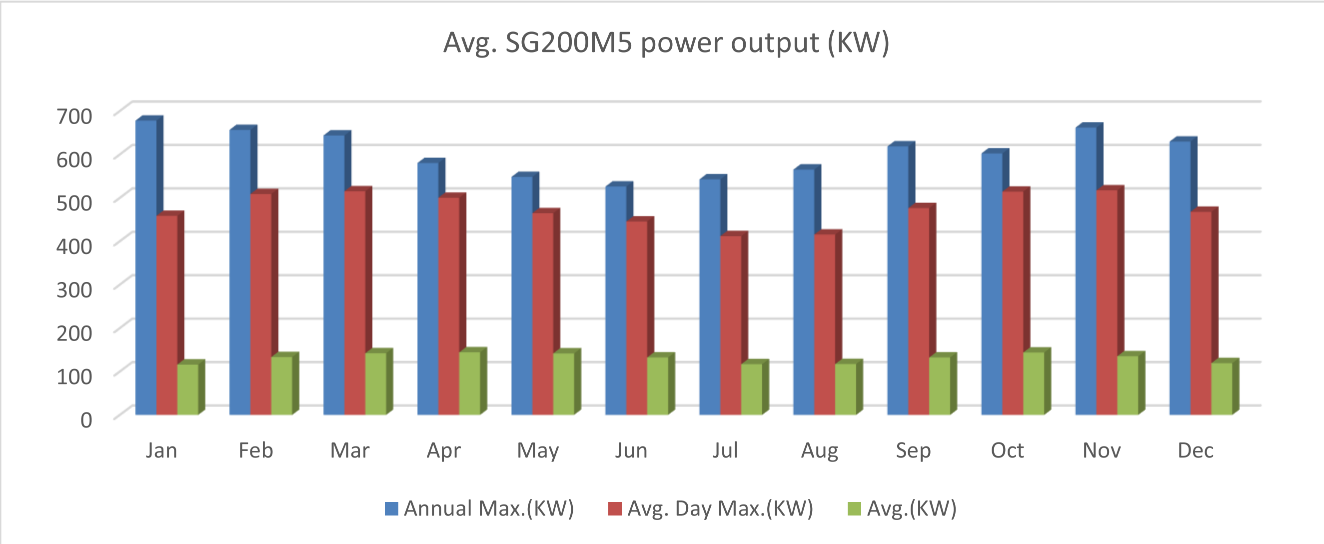

FIGURE 8. **The average power output of PV radiation in KW.**

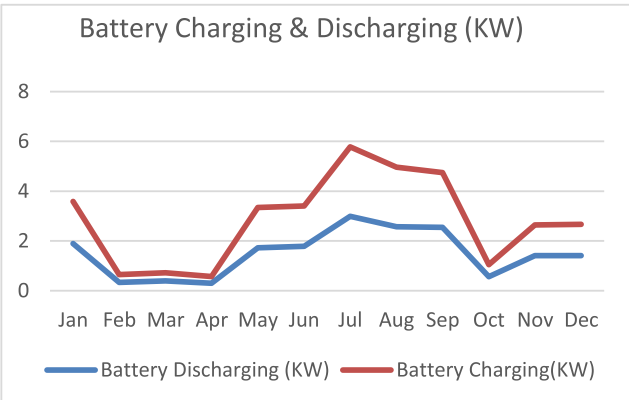

FIGURE 9. **Charging and discharging of batteries on a monthly basis.**

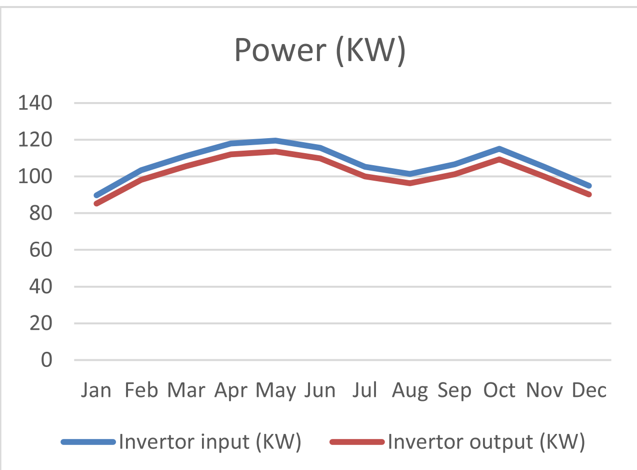

FIGURE 10. **Average monthly input and output power of the inverter (KW).**

costs as defined in [44]:

$$\boldsymbol{NPC} = \frac{\boldsymbol{C_{T-ann}}}{\boldsymbol{CRF(i,t)}} \tag{1}$$

where:

C_{T-ann} = The system's annualized total cost.

CRF = Capital recovery factor

i = Annual Interest Rate (also known as Discount Rate)

t = the project's lifespan.

The sum at the end of the year in which interest is paid or earned is used to calculate the yearly effective interest rate:

$$i = \frac{i' - f}{1 + f} \tag{2}$$

where:

i' = Nominal interest rate

f = Annual inflation rate

The number of yearly payments at a discount rate necessary to reach the present value after a specified number of years is known as the capital recovery factor. It comes from equation (3):

$$CRF\,(i,n) = \frac{i\,(1+n)^n}{(1+n)^n - 1} \tag{3}$$

where n = Year's number.

2) COST OF ENERGY (COE)

The HOMER software utilizes Equation (4) to compute the COE by dividing the annual cost of electricity production by the total electric load served, which represents the overall cost minus the expenses related to serving the thermal load.

$$COE = \frac{C_{T-ann}}{E_{off-grid} + E_{on-grid}} \tag{4}$$

where:

$E_{off-grid}$ = electrical energy from the grid.

$E_{on-grid}$ = the total amount of electricity sold to the grid from microgrids.

TABLE 3. Production and consumption of energy for the optimal system.

Category	PV (KW)	Battery (kWh)	Grid (KW)	Convertor (KW)	Net Present Cost ($)	Cost of Energy ($)	Operating Cost ($/Year)	Capital Cost ($)	Renewable Fraction (%)
01	944	98	ON	348	$483,112	$0.0176	$2,816	$412,702	99.3
02	629	1,179	ON	418	$599,053	$0.0242	$6,228	$443,348	99.5
03	944	786	ON	418	$610,593	$0.0198	$4,300	$503,090	99.7
04	944	1,179	ON	18	$669,383	$0.0218	$5,064	$542,783	99.8
05			ON		$1.89M	$0.22	$75,756	$0	0

3) OPERATING COST (OC)

HOMER provides a definition for (OC), which involves calculating the total yearly expenses and income while excluding the initial capital investment. The operating costs are determined using Equation (5).

$$C_{opreatin} = C_{\text{ann,tot}} - C_{\text{ann,cap}} \tag{5}$$

where:

$C_{\text{ann,tot}}$ = overall system annualized cost ($/year),
$C_{\text{ann,cap}}$ = overall capital cost on an annual basis ($/year).

4) CAPITAL COST (CC)

The HOMER program defines the notion of initial capital cost as the complete installed expense incurred at the project's outset.

5) RENEWABLE FRACTION

The HOMER program defines the renewable fraction as follows. The renewable fraction refers to the proportion of energy delivered to the load that originated from renewable power sources. Equation (6) is used to compute the renewable fraction.

$$f_{ren} = 1 - \frac{E_{nonren} - H_{nonren}}{E_{served} - H_{served}} \tag{6}$$

where:

E_{served} = the total serviced electrical load (kWh/year).
H_{served} = the entire thermal load that was used (kWh/year).
H_{nonren} = the non-renewable thermal production (kWh/year).
E_{nonren} = the generation of non-renewable electricity (kWh/year).

III. OPTIMIZATION OF MICROGRID

The main goal is to continuously supply RIU's Lahore campus with the electricity it needs. To handle the load, several sources are considered and employed. An inexpensive and reliable power source is provided by optimizing this power system's design. For this, a number of sources are combined with information on their structure, availability, and current market and operating pricing. The "HOMER Optimization" feature was utilized, enabling the HOMER software to find the most favorable upper and lower limits for each energy source. Through extensive simulations, the HOMER software proposed the best microgrid configuration, as shown in Table 3. This configuration was assessed using five key performance indicators: NPC, COE, OC, CC, and Renewable Fren. The HOMER software recommended five optimized microgrid designs for RIU's Lahore campus. Sensitivity analysis in HOMER-Pro software entails studying how alterations in parameters within an optimization problem impact both the value of the objective function and the point where the optimal solution is achieved.

This approach ensures a dependable and cost-effective supply of electricity from sustainable energy resources by considering sensitivity and decision variables during the optimization process. In this research work, solar illumination, battery cost, the atmospheric temperature, and PV cost have been identified as sensitivity parameters. The size of the PV module, AC to DC converter, generator, batteries, and grid supply are considered as decision variables, given the limited availability of the national grid in certain areas. These decision variables are crucial to consider. Five microgrid designs underwent evaluation based on diverse assessment standards, including COE, NPC, Renewable Fraction, CC, and OC. Table 3 displays the outcomes of the sensitivity analysis for these microgrid models. The most feaseble configuration includes the combination of the grid network with battery storage, PV system, and power converter. The optimal configuration of the system is proposed by HOMER, which is listed in the first row of Table 3. This configuration offers incessant backup with an essential energy storage system.Table 4 provides an evaluation of the hybrid microgrid based on its operation, capital and maintenance (O&M) costs. The solar

TABLE 4. Cost of the proposed optimal configuration.

Component	Capital ($)	Replacement ($)	O&M ($)	Salvage ($)	Total ($)
Storage System	$9,898	$9,898	$0	$3,299.33	$16,496.67
Solar Photovoltaic	$298,304	$0	$236	$49,717.33	$248,82.67
Power Converter	$104,500	$104,500	$0	$34,833.33	$174,166.67
Grid	$0	$0	$43,626.42	$0	$43,626.42
System	$412,702	$114,398	$43,862.42	$87,850	$483,112.42

TABLE 5. Production and consumption of energy for the optimal system.

Production & Consumption	Components	kWh/Year	Percentage (%)
Production	Solar Photovoltaic	1,616,771	99.5
	Grid	7,932	0.488
	Total	1,624,703	100
Consumption	AC Primary Load	344,195	33.4
	DC Primary Load	0	0
	Grid Sales	755,768	68.7
	Total	1,031,775	100

photovoltaic system incurs the maximum capital cost, while the national grid has the highest O&M cost. The total system's cost for the one year is assessed to be $483,112.42. A one-year assessment of the proposed microgrid has also been conducted, and Table 5 presents a comparison based on energy production and consumption. The 99.3% of the total energy in the proposed microgrid system is produced by solar PV and given directly to the load. The national grid provides the remaining 0.7% of the nation's electricity. This shows that the grid is active when there is no light or only dim light as a result of bad weather.

TABLE 6 compares the economics of all the microgrid categories and optimal scenarios that have been proposed. The findings revealed that among the five designs, HOMER's initial optimal microgrid design exhibited the shortest period required to recoup the initial investment, the most substantial return on investment, and the greatest current and annual value. These results further bolster its suitability for the specific location.

IV. DISCUSSION

In countries like Pakistan, such as other developing nations, significant energy challenges prevail, including grid power outages, escalating energy expenses, uncertainty surrounding conventional energy sources, and greenhouse gas emissions. Currently, a major global focus lies in addressing the issue of securing a continuous and reliable energy supply while maximizing the use of renewable energy sources at minimal cost. In this research, an optimal hybrid microgrid system is suggested for Riphah International University's campus in Lahore, utilizing the HOMER Pro Software. The study incorporates first-year measurements of the university's load and forecasts data for sun light, temperature, battery life and load for the subsequent 25 years. Using all the available resources (solar, wind, diesel generator, grid, and battery bank), HOMER simulates a microgrid and proposed the optimal design after conducting 932 successful simulations. This is followed by a comprehensive economic study to meet Riphah University's energy requirements with reliable supply

TABLE 6. Economic comparison of proposed five configurations of microgrid.

Metric	Category 01	Category 02	Category 03	Category 04	Category 05
Present Worth ($)	1,409,960	1,384,396	1,282,480	1,223,690	0
Annual Worth ($/year)	56,398	55,376	51,299	48,948	0
Return on Investment (%)	17.2	15.5	13.6	12.3	N/L
Simple Payback (year)	5.58	5.94	6.72	7.22	N/L

at the lowest possible costs. The evaluation of every microgrid design's performance involves considering multiple assessment criteria, including COE, NPC, Renewable Fraction, OC, and CC. The economic analysis encompasses various influences, such as capital cost, replacement cost, fuel cost, energy cost, OC, maintenance cost, NPC, annual worth, return on investment, present worth, and payback period. After an extensive analysis across all the mentioned benchmarks, the proposed optimal hybrid microgrid design is selected based on its performance, applicability, and reliability.

The most effective combination of elements includes the grid network, solar system, power converter, and battery bank. The decision is determined by considering five parameters: COE, NPC, CC, OC, and Renewable Fren. Along with the required energy storage system, this setup also integrates a continuous backup system. Among these, the solar system has the highest CC as well as the greatest salvage amount. The system will cost $483,112.42 in total for one year, according to calculations. 99.3% of the total energy used in the proposed microgrid's design is produced by solar photovoltaic energy and delivered directly to the load. The national grid provides the remaining 0. **488**% of electric energy. This illustrates how the grid operates when there is no light or only dim light as a result of changing weather conditions. Also, a financial analysis of all the suggested ideal hybrid microgrid situations and categories is done. Among the five suggested designs, HOMER's optimal hybrid microgrid design distinguishes itself by having the shortest payback period, the highest return on investment, and the greatest present and annual value. These favorable factors make it even more suitable for the specific location site.

V. CONCLUSION AND FUTURE RECOMMENDATIONS

The primary goal of this research work is to design an optimized model for a microgrid that ensures a continuous electricity supply at the lowest cost possible. This design incorporates an efficient energy management system and has undergone thorough analysis and verification under various benchmarks, scenarios, and conditions to ensure its effectiveness. Initially, the load of the RIU university is measured continuously for one year. The proposed microgrid system, comprising national grid with a solar photovoltaic systema, power converter, and storage system has been identified as the most effective integration of power sources to meet the energy demands of the Riphah International University, Lahore campus without any interruptions for the next 25 years. By achieving a 99.3% fraction of renewable energy, this system advances clean and environmentally friendly energy generation while minimizing greenhouse gas emissions. The optimal operation and capacity of the microgrid were critical factors in maximizing the benefits obtained. To fulfill the study's objective, the HOMER software was utilized to conduct the simulation, optimization, and design of the suggested microgrid.

The simulations procedure conducted using HOMER Pro software and 932 models with different capacities were proposed by the software. Through an extensive economic analysis, considering energy demand, weather predictions, anticipated network outages, and PV module degradation effects over the system's 25-year lifespan, the most cost-effective combination of energy resources capable of supplying continuous power for 25 years was selected. Based on these analyses, it was determined that a 944 kW solar (PV) power source, and a 98 kWh energy storage unit constitute the most optimal configuration for the specified load profile. In the proposed optimal design of the microgrid, 99.3% of total energy is generated by the solar photovoltaic and supplied to the load directly. The remaining 0.70% of electric energy is supplied by the battery and grid. The study also investigated the impact of PV module deprivation, increases in energy demand, and network outages on a hybrid microgrid system containing of PV, battery backup, and a converter. The proposed configuration, which includes national grid, a 98 kWh battery bank, and a 944 kW PV system, was found to be the best solution for fulfilling the energy requirements of RIU, Lahore campus over the designated lifespan.

In the future, the study can be employed to look into a comparison of off-grid and grid-connected solutions for different places. Furthermore, to investigate the best hybrid design, hybrid systems with other renewable energy sources like biomass, tidal, geothermal and wind could be integrated on different locations.

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OSAMAH KHALED received the B.Sc. degree in electrical and telecommunication engineering from the University of Engineering and Technology, Peshawar, and the M.Sc. degree in electrical engineering from Riphah University, Lahore. He is an Engineer Designer with ED Energy Ltd., Pakistan. His research interests include renewable energy, artificial intelligence, wireless communication, and microstrip resonator-integrated antennas.

MUHAMMAD ZAHID received the bachelor's degree in electrical engineering from The University of Lahore, Pakistan, in 2012, the master's degree in electrical power engineering from COMSATS University Islamabad, Pakistan, in 2015, and the Ph.D. degree in electrical engineering from the Huazhong University of Science and Technology, China, in 2018. He is currently an Assistant Professor with the Department of Electrical Engineering, Riphah International University, Lahore Campus, Pakistan, where he is also a graduate program in charge. His research interests include smart grids, microgrid operation and control, power quality, FACTS devices, and distribution network modeling and planning.

TAUSIF ZAHID received the B.Sc. degree in electronic engineering from COMSATS University Islamabad, Abbottabad Campus, in 2009, the M.S. degree in computer networks from the KTH Royal Institute of Technology, Sweden, in 2011, and the Ph.D. degree in electrical engineering from the School of Electronics and Information Engineering, Huazhong University of Science and Technology (HUST), China, in 2016. During the Ph.D. studies, his research was regarding the design and implementation of software-defined home networks. He is currently an Associate Professor and the Head of the Department with the Riphah International University, Lahore Campus, Pakistan.

TEHSEEN ILAHI received the B.S. degree in engineering (electronics) from the Sir Syed University of Engineering and Technology, Karachi, Pakistan, and the M.Sc. degree in engineering (energy) from the University of Engineering and Technology (UET) Lahore, Lahore, Pakistan, in 2016, where he is currently pursuing the Ph.D. degree in electrical engineering. He is a Faculty Member of the Department of Electrical Engineering, Riphah International University, Lahore Campus, Pakistan. His research interests include electric vehicle charger design, power electronics converters, smart grids, analog and digital electronic circuits, and renewable energy technologies.