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TECHNO ECONOMIC AND ENVIRONMENTAL ANALYSIS OF REPLACING DIESEL WITH NATURAL GAS POWER GENERATOR IN AN EDUCATIONAL INSTITUTION

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ABSTRACT

Growing urban pollution concerns necessitate solutions for power generator emissions. Transitioning from Diesel to natural gas generators offers a cost-effective and eco-friendly alternative. This research evaluates the feasibility of using natural gas generators to power institutions during grid disruptions, focusing on efficiency and emissions. Natural gas generators have advantages, including higher energy content per unit, reducing fuel consumption and emissions. Their superior power-to-weight ratio provides greater output for their size and weight. Adopting natural gas generators offers institutions a greener choice, reducing carbon footprints and enhancing energy efficiency. Findings shed light on environmental and financial impacts within microgrid systems, informing sustainable, cost-effective energy decisions. Research indicates significant cost savings, with natural gas generators potentially reducing expenses by nearly 50%. In contrast, Diesel generators emit harmful gases, such as carbon monoxide, unburned hydrocarbons, particulate matter, sulfur dioxide, and nitrogen oxides. In summary, natural gas generators provide a compelling case for institutions seeking cost-effective, environmentally friendly solutions. This transition can cut Net Present Cost (NPC), Cost of Energy (COE), and overall operating costs significantly, nearly halving them compared to Diesel generators. Furthermore, ongoing operational expenses for natural gas generators remain minimal, even considering fluctuating Diesel fuel prices. Embracing natural gas generators signifies a sustainable and cost-effective move towards a cleaner, more efficient energy future.

Keywords: Natural gas generator, Diesel generator, grid outages, economic analysis, sensitivity analysis, HOMER pro software.

INTRODUCTION

Delhi, India's capital, is one of the most polluted cities on the planet. The major sources of pollution in Delhi are vehicular emissions, industrial activities, construction sites, and burning of agricultural waste. The health of the people living in Delhi is seriously threatened since the air quality index (AQI) there frequently exceeds the harmful limit. Asthma, heart disease, and cancer have all been linked to Delhi's high levels of air pollution, among other health issues. Children and the elderly are particularly susceptible to pollution's negative effects. The pollution also affects the productivity and economic growth of the city. To combat the pollution problem, the government has implemented several measures such as banning the use of firecrackers during festivals, implementing odd-even schemes for vehicles, and shutting down polluting industries. However, the pollution levels continue to remain high.

In addition to the aforementioned sources of pollution, another significant factor in Delhi's air pollution is the usage of Diesel generators. During power outages, Diesel generators are often employed as backup power sources in buildings and houses. In any case, these generators emanate hurtful poisons such as nitrogen oxides, particulate matter, and carbon monoxide. The use of Diesel generators has been banned in certain areas of Delhi, but enforcement of the ban has been weak. The government has also encouraged the use of cleaner alternatives such as solar power and battery backups.

To meet the demand of electricity, use of Diesel generators in Delhi has increased drastically. Diesel generators are being used in National Capital Region from many decades. Knowing that Diesel generators are known as one of the main factors for contaminating air. On the basis of a formal order, the Central Pollution Control Board of Delhi NCR has authorized the increase of parking charges by up to four times in Delhi NCR, the measures laid down in the Graded Response Action Plan of Delhi NCR, when the air quality deteriorates significantly [1] Since Delhi is a non-attainment city. Non-attainment cities are those which have been reliably appearing poorer air quality than the National Encompassing Air Quality Measures. Diesel generators are known to contribute to air pollution. A study was done for the Faridabad Industrial area, it encompasses Ballabgarh and Faridabad and is home to over 1000 air-polluting companies. It was surprising to see that enterprises in the area employed more than 1,000 DG sets, given that use of coal, and more resources in power plants and thermopacks is thought to be a significant contributor to air pollution. These 378 MW-capable DG units devour 1.4 lakh tons of fuel annually. This represents around 60–70% of the region's annual liquid fuel consumption. According to CSE, fuel burning is responsible for 50% of the airborne particulate matter and Sulphur dioxide load [2]. A research group in Delhi named CSE conducted a separate research named Possibility evaluation: Switching Diesel-based with gas-based generators that showed DG sets altogether contributed to air contamination within the region. Since March 22, 2022, the cost of Diesel fuel is rising, and by March 31, 2022, the price of Diesel has increased cumulatively to Rs 5.70 per litre. Due to increasing input costs, which fleet operators must pass along to their clients, the most recent Diesel price increase may cause truck rents to increase by at least 2-3% [3]. Various research has been done in the field of combined cooling, heat and power (CCHP). The following are some research papers related to CCHP/trigeneration. Techno – economic study on Indo-German Trigen project was done. Its main aim was to utilize the heat from the power generation and increase the overall efficiency to 90%. The project was executed by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in a government hospital in New Delhi [4]. On gas power generation projects that took into account reducing carbon emissions, economic analysis and policy recommendations were made. Its main aim was to find a cleaner source of energy i.e. Natural Gas which produces minimal amount of harmful gases. This is required as climate change is happening in the world due to high carbon emission and every country is taking steps to reduce carbon footprint. So, as China`s primary energy consumption is mainly dependent on coal, it is being pressurized to reduce dependence on coal for energy production. On gas power production projects that considered reducing carbon emissions, economic analyses and policy recommendations were made. On the project's net present value (NPV), sensitivity analysis and a probabilistic risk assessment are carried out. According to algorithm study, the cost of natural gas and the cost of using the grid have a big impact on how economically efficient gas power production projects are. Additionally, the impact of government activities on ventures is outlined, and a few workable approach proposals are made [5]. Concurring to the consider, introducing high-efficiency natural-gas generators for combined warm and control in homes can altogether cut back on both essential vitality utilization and CO_2 emanations. However, the payback period varies depending on several parameters such as electricity and gas prices, equipment costs, and climate conditions. The study recommends that policymakers should consider these factors when promoting the adoption of CHP systems in residential areas. In general, the consider emphasizes the significance of embracing economic vitality practices in private zones to decrease CO_2 outflows and essential vitality utilization. It requires a concerted effort from all stakeholders, including the government, utilities, homeowners, and communities, to promote the adoption of CHP systems and other sustainable energy solutions for a cleaner and healthier environment [6].

Till now there is very little research that has been carried out for replacing Diesel genset with natural gas generator. Some of them are "Is it the right time now to replace the Diesel system with the natural gas system at Al Duqm in the Sultanate of Oman?" [7]. "Techno-economic assessment of pathways for liquefied natural gas (LNG) to replace Diesel in Canadian remote northern communities" [8]. In this study, biogas was used instead of Diesel to provide heat and electricity. In this extend, the analysts come to the conclusion that, in terms of cost-savings proportion and carbon dioxide comparable decrease proportion, the biogas CHP framework would be ideal to the vitality framework that was already utilized. Another crucial conclusion is that switching from conventional technology to biogas CHP reduces CO_2 emissions in this 375-kilowatt generating CHP system by 529.65 tons annually [9]. This study demonstrates the potential for biomass energy in India's rural areas. According to the assessment made in the study, a significant portion of the share of bioenergy can be routed through current bioenergy technology (BET), and a sizeable portion of the share of fossil fuels can be converted to modern BETs. This is feasible with lower total economic costs and greater advantages for combating climate change. If the potential of BETs is used, there will be advantages for the environment in the form of a reduction in carbon emissions of 110 T C per year. [10]. This study demonstrates the potential of using renewable energy as a replacement or addition to the two generators erected to power a inaccessible island within the Indian Sea. It was decided that it is conceivable to set up a renewable vitality framework on the island that can be hybridized with the Diesel-powered generator that has as of now been put on the island by utilizing the Homer Professional computer program to look at all potential results [11]. In a term paper, the year-round pump stack was modeled utilizing Homer Pro to survey the practicality of exchanging from Diesel water system pumps to sun based PV fueled motor-pump frameworks. It was found that this should be done, which employing a bigger water holding tank is additionally vital. A larger holding tank can reduce emissions of carbon dioxide and excess electricity fractions to 0% [12]. With the objective of helping country inhabitants, a ponder was conducted to address the optimization of net show taken a toll (NPC), fuel fetched, operation fetched, and fetched of vitality (COE) of the cross breed framework composed of photovoltaic (PV), wind turbine generator (WTG), Diesel generator, and battery capacity framework. It was determined that because of their numerous advantages and favorable effects on the environment, sources of clean energy are potential substitutes for supplying rural populations' energy needs [13]. A research paper was prepared to compare the consequences of using fuel oil, bioDiesel, and natural gas in an optimum hybrid system made up of solar PV, wind, battery, and a Diesel generator in place of petroleum Diesel. Analysis has been done on the effects on overall Net Present Cost (NPC), pollutant emissions, and optimal system sizing. In comparison to elective frameworks that utilize Diesel, natural gas, or fuel oil, it was found that bioDiesel is the foremost financially sound choice. Additionally, bioDiesel has the lowest CO_2 emissions, but the one drawback is that it also has the greatest nitrogen oxide emissions [14]. Implementing HOMER Pro software, a think about was conducted to assess the specialized and monetary viability of implementing a decentralized hybrid energy system in Nigeria's northern region. The results illustrate that the PV/ Generator/Battery crossover vitality framework could be a workable vitality framework at the display contract rate and cost of Diesel in Nigeria. When compared to an energy system that relies solely on generators, adopting a hybrid energy system results in much lower electricity production costs. As a result, we may employ cheaper and cleaner forms of energy, which leads to an essential conclusion [15]. According to the modeling results, the NPC and COE of a hybrid system with an RF of 9% are US123,231,728 and 0.27, respectively. This is significantly less than the cost of a gas-only system (RF = 0%), which would be much higher. As a result of the addition of PV, the hybrid system used less natural gas than a gas-only system, which resulted in a 7.2% decrease in the amount of air-polluting gases released into the atmosphere. Because it is a more efficient and cost-effective way to generate electricity, our analysis recommends that a PV hybrid power system be put into place [16]. The energy demand of a retail mall was simulated in HOMER as part of a study to compare the costs of various self-generation systems. Renewable electric units are a superior option for the electric network due to their low operational costs, continuous operation, and reasonable supply to the network. However, they are inefficient during electrical grid breakdowns as they cannot generate large amounts of energy quickly. [17].

In this study we have carried out the simulation cum performance test of 2 generators one work on Diesel fuel while the other uses natural gas as fuel. Using HOMER Pro software, hybrid energy systems to fulfil the campus's electricity needs with a system independent of the grid were assessed from a technical and financial standpoint under various scenarios. Considering the sensitivity analysis, emission, fuel consumption, electric consumption, efficiency, cost component etc. The systems consist of mainly 3 components, a generator, electric load(kwh/day) and a grid.

MODELING

HOMER is a microgrid software that is used to design and deploy microgrids and distributed power systems. It serves as the industry benchmark for improving microgrid designs in every industry, from grid-connected campuses to military bases, and from village power to island utilities. Storage, fossil-based generation, and renewable energy sources can all be combined in HOMER [18]. By estimating the energy flows to and from each part for each time period, it compares production and consumption. The battery and generator operation schedules are likewise determined by the software. It makes projections for the system's lifetime costs of capital, replacement, operation, maintenance, fuel, and interest. It has a convenient interface that allows users to easily generate and analyze energy models. It uses advanced algorithm and simulation techniques to provide efficient results, helping users make accurate decisions about energy usage and efficiency. It includes vast database of energy technologies and resources, making it easy for users to find and compare different options.

LOCATION OF THE PROJECT

Delhi Technological University (DTU) formerly known as “Delhi college of Engineering” is under developing stage, which means demand of electricity will also increase and so the load on grid be, which may lead to power cut off. In that case need of generator is essential to fulfill electrical requirement of institutions. For the best use of energy, location is crucial. The location has a considerably greater influence on the systems engineering than other variables, such as the environment, the type of load used, the climate, and whether the site is in an urban or rural region. The site of the proposed system's case study is Delhi Technological University Bawana Road, Shahbad Daulatpur Village, Rohini, Delhi 110042. Figure 1 shows the satellite view of DTU campus. Its coordinate is 28°44′59.81″N 77°7′1.30″E. The climate in Rohini is classified as humid subtropical with dry winters. The district's average annual temperature is 31.32 °C (88.38 °F), which is 5.35% higher than the country's average. 13.96 millimeters (0.55 inches) of precipitation fall on Rohini annually, and there are 20.0 rainy days, or 5.48% of the time.

Rohini is a suburban range located within the northwest area of Delhi, India. The climate of Rohini is similar to that of Delhi, with three main seasons: summer, monsoon, and winter. Summer in Rohini starts from April and lasts until June. During this season, the temperature can rise up to 45°C (113°F) with high humidity levels, making it extremely uncomfortable for people. The hot winds from the neighboring Thar Desert add to the heat, making it one of the hottest areas in Delhi. The monsoon season in Rohini starts from July and lasts until September. During this season, the area receives an average rainfall of around 650 mm (25.6 inches). The rainfall brings relief from the scorching heat, but it also causes waterlogging and traffic jams in the area. Winter in Rohini starts from November and lasts until February. The temperature during this season scale from 5°C (41°F) to 25°C (77°F). The area experiences dense fog during this season, which often leads to flight delays and cancellations. Overall, the weather in Rohini is similar to that of Delhi. The mean ambient temperature of Rohini varies depending on the season. During summer, Average temperatures can fluctuate 35°C (95°F) to 45°C (113°F). Average temperatures during monsoons scale from 30°C (86°F) to 35°C (95°F). And meanwhile in winter, normal temperatures scale from 10°C (50°F) to 20°C (68°F).

Figure 1: Satellite view of DTU campus. [19]

Figure 2 represents the ambient temperature of the region selected for research work. The yellow bars represent monthly mean daylight, red line represents monthly mean ambient temperature (in °C) and green line represents Earth skin temperature (in °C).

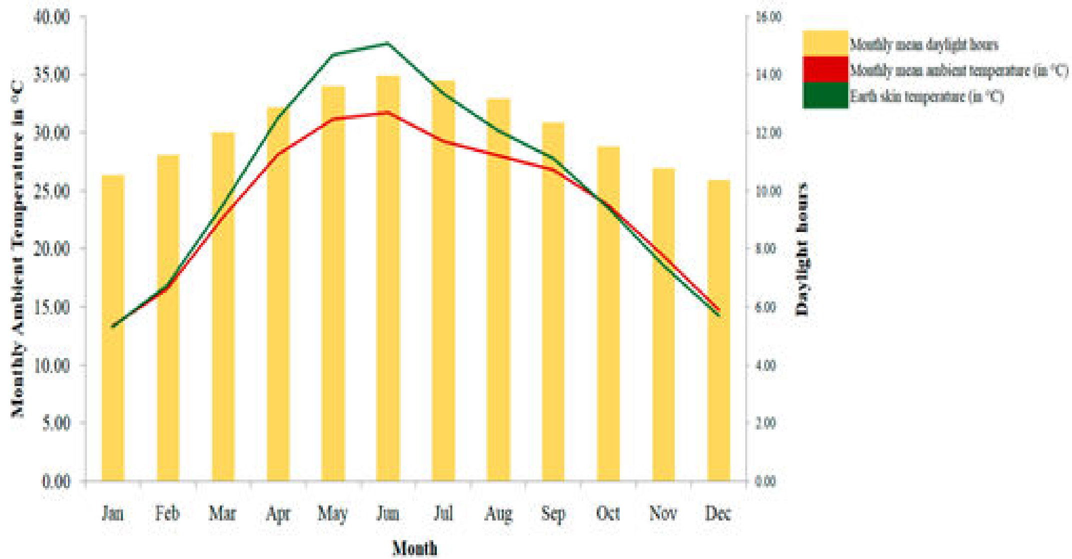

Figure 2: Month wise mean ambient temperature, daylight hours and earth skin temperature of the selected region. [20]

METHODOLOGY

The systematic and organized approach used to carry out research or find a solution to a problem is referred to as methodology. In order to gather, analyse, and interpret data and draw valid and trustworthy conclusions, a variety of processes, techniques, and tools are used. A crucial component of research is methodology, which makes sure that the investigation is thorough, open, and repeatable.

This project's evaluation requires relevant data and site to study the operational data at different framework precisely. During the optimization phase, several system configurations that adhere to technological limitations and meet the necessary energy demand are simulated. Finally, a number of these improvements are carried out based on the sensitivity analysis' variable inputs. HOMER carries out the following four calculations: NPC, initial investment cost, COE, and expenses for operations and upkeep (O&M) [21,18]. HOMER software's procedural flow diagram is shown in figure 3. In this study we have gathered information about electric components like total electric consumption (kWh) and electric charge from DTU campus Junior Engineer (electrical) to get desired and optimized results. Further we took a grid and a generator which will satisfy the need of electricity in campus when grid is not supplying electricity.

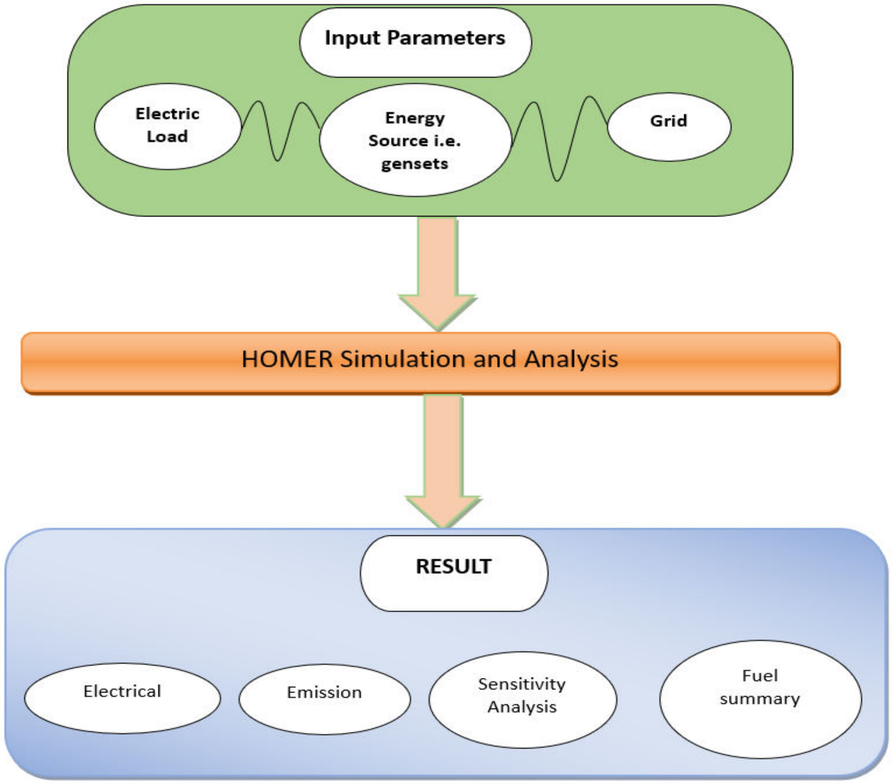

Figure 3: HOMER Pro software's procedural flow for improving the system.

System Description

The system under consideration is a microgrid that consists of a grid, generator, and an electric load. The network is the essential source of control for the microgrid, which gives power to the institution. The generator serves as a reinforcement control source and gives power to the microgrid when the grid isn't operational or incapable to meet the load request. The electric load in the system represents the energy consumption of various appliances and devices connected to the microgrid. The load can vary depending on the time of day and the season, and it can be controlled by a load management system to optimize energy consumption and reduce costs. In this study, we will be using model as shown in Figure 4 and Figure 5 for two different kind of generators.

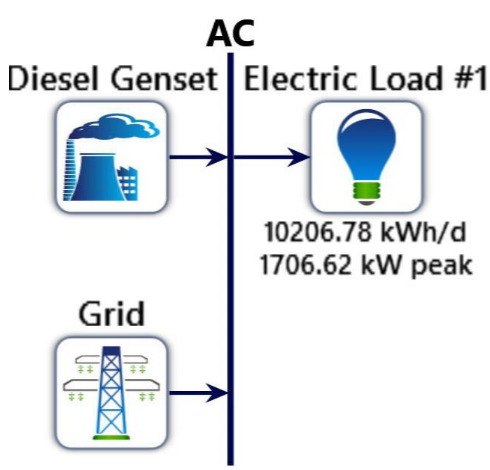

Figure 4: System model for Diesel Generator. [18]

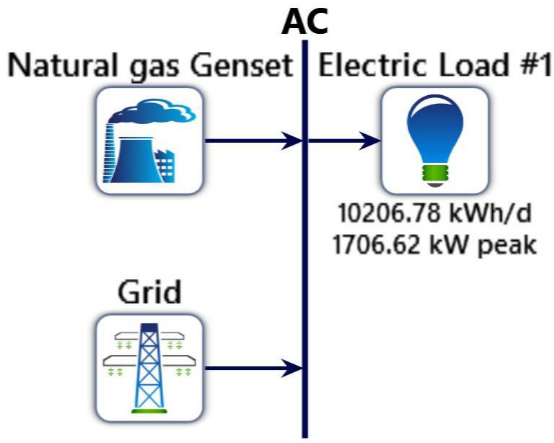

Figure 5: System model for Natural gas Generator. [18]

Load Profile

Table 1 represents month wise total electricity consumption (kWh) for year 2021 and 2022 respectively. This data is provided by university officials.

Load profile of an educational institute is completely different from residential, industrial and commercial loads. Monthly load profile of the education institution may vary on the basis of semester duration, vacations etc. The month to month load profile for a year is appeared in Table 1. Figure 6 portrays that the demand is at its peak in the month of June, July, August and September i.e. nearly 407.71KW because according to climatic conditions of the location, the summer season and humidity is at its peak because of which institution has to use air conditions, water coolers etc. In contrast, the load demand is typically lower in the winter months when heating systems are used more frequently. Figure 7 represents the yearly load profile of campus. Also, in the month of July, newly admitted student came to institution for which institution organize multiple orientations in multiple auditoriums which require a high amount of electricity to run at its best. The annual scaled average is 10206.78 KWh/day. In this study, we have used 2 different generators for two different scenarios. In one scenario we will be using Diesel generator and in other scenario we will be using Natural gas generator. The cost value for the Diesel generator was $120,000; the replacement cost estimate was $96,000; and the O&M cost estimate was $0.100 per operational hour (op.hr.). The capital cost valuation for the natural gas generator was $180,000, the replacement cost was $144,000, and the O&M expenses was $0.050 per operational hour (op.hr.).

As we all know that electricity doesn't come to our area at all point of time, sometimes it may cut down and sometimes it may differ from location to location. In this study we have done electricity outrage from 1100hrs to 1300hrs to study about the different aspects of Diesel and natural gas generators. Keeping in mind that no energy is sold to the grid when generator is on. Figure 8.

Table 1: Total electricity consumption values by months (kWh) for the year 2021 and 2022. (DTU campus)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Electric Consumption (2021)	182220	216840	191820	91860	191820	91860	191760	270660	236700	198520	220140	149160
Electric Consumption (2021)	250020	210002	239400	418440	582967	565800	579900	604140	696120	694620	465780	364680

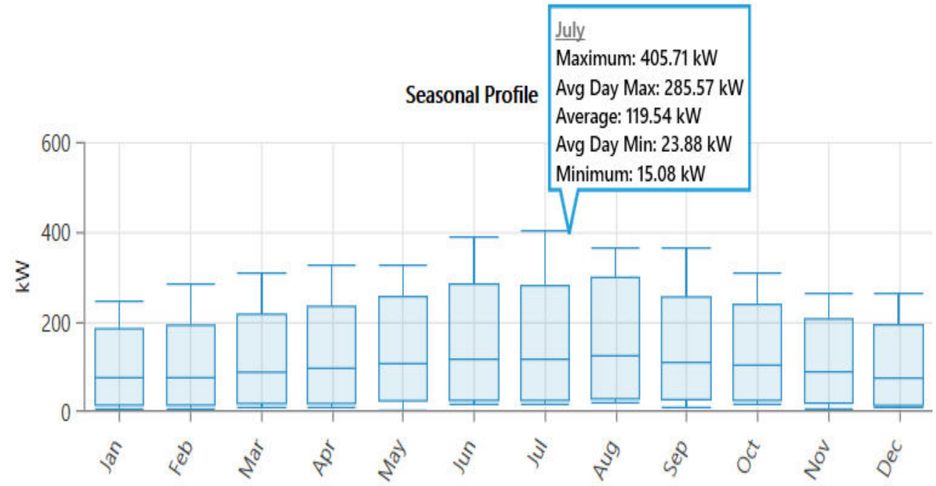

Figure 6: Seasonal load profile. [18]

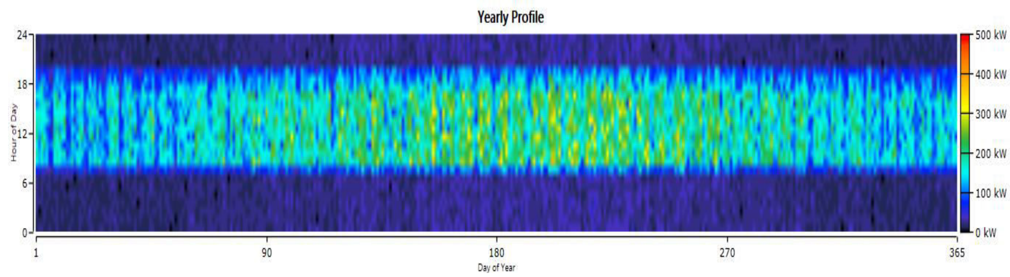

Figure 7: Yearly load profile. [18]

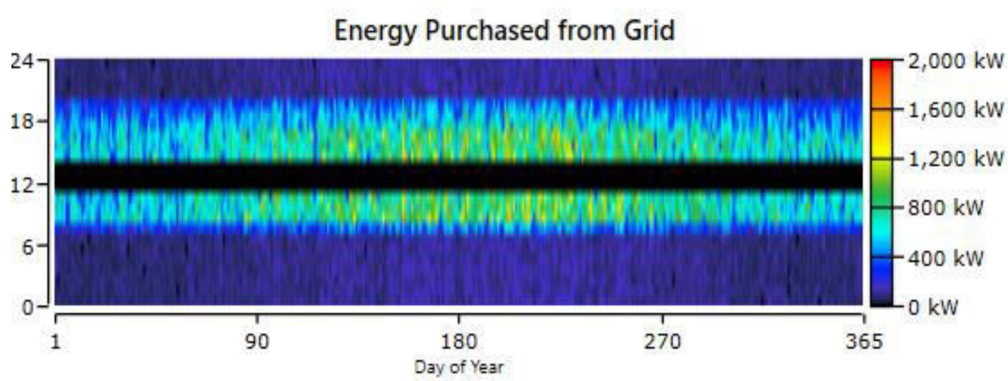

Figure 8: Energy purchased from grid. [18]

Generators

In this analysis, we used 2 generators in 2 different scenarios. In the first scenario, we use a Diesel generator "CAT-1825kVA-50Hz-PP" with a capacity of 1460 KW. Its cost is estimated at $120,000 and assumes a replacement cost of $96,000, or 80% of the original cost. In the second scenario, we use the natural gas generator "CAT-NG-1875kVA-50Hz-CP" with a capacity of 1500 KW. Its cost is estimated at $180,000 and replacement cost at $144,000. The HOMER Pro library contains references to both generators. Figure 9 and Figure 10 represents that efficiency of natural gas generator is greater than Diesel generator. Typically, since natural gas encompasses a higher vitality substance content substance synonyms per unit than Diesel, which suggests that less fuel is required to deliver the same sum of vitality. Additionally, natural gas generators have a higher power-to-weight ratio than Diesel generators, meaning that they can produce more power for their size and weight. This translates into lower fuel consumption and lower emissions, making natural gas generators a more environmentally friendly option. However, the efficiency of both types of generators depends on several factors such as the load, operating conditions, and maintenance practices.

COST ANALYSIS

In this section the economic analysis is presented in terms of net present cost, cost of energy and sensitivity analysis.

Net Present Cost (NPC)

A budgetary calculation known as net present cost (NPC) is utilized to appraise the show esteem of costs related to a certain extend or speculation. It considers the time esteem of cash, which states that owing to swelling and other factors, cash earned or went through within the future will be worth less than cash picked up or went through nowadays.

Each future cash stream related to the venture or venture is reduced back to its current esteem employing a rebate rate to decide the NPC. This incorporates both costs and incomes. The whole of all marked down cash outpourings (costs) is subtracted from the whole of all discounted cash inflows (incomes) to reach at the net present value (NPV). In the event that the NPV is positive, it demonstrates that the venture or speculation is anticipated to create a profit, whereas a negative NPV proposes that it'll result in a misfortune.

NPC is commonly used in capital budgeting and investment analysis to help decision-makers evaluate the financial viability of different projects and investments. It allows them to compare the costs and benefits of different options on an equal footing by accounting for the time value of money. In Eq. 1, the highest NPC is taken into account as an alternative.

$$NPC = PV(Benefit) - PV(Cost) \qquad (1)$$

$$NPC = \sum_{n=k+1}^{t} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{k} \frac{C_n}{(1+i)^n} \qquad (2)$$

Here, Bn and Cn represent the benefit and cost values, respectively, for the n years of the systems' lifespan Eq. (1) is thus taken into account for the price term. The system's initial investment cost, which includes power costs for installation and operation, makes up the primary cost factor. The system lifespan used in this investigation was set at 25 years.

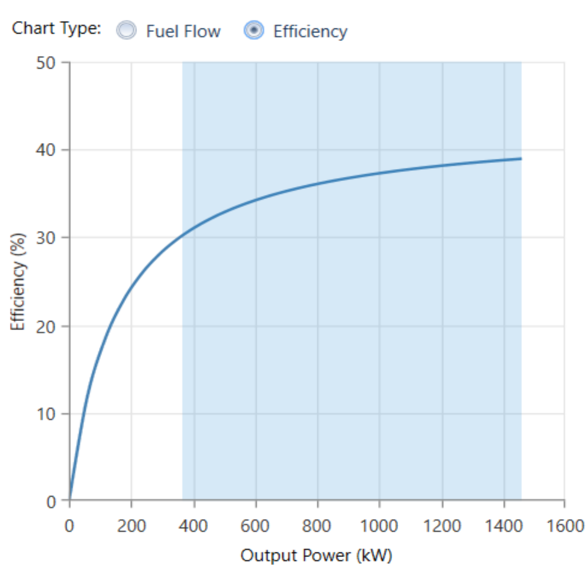

Figure 9: Efficiency graph of Diesel generator used. [18]

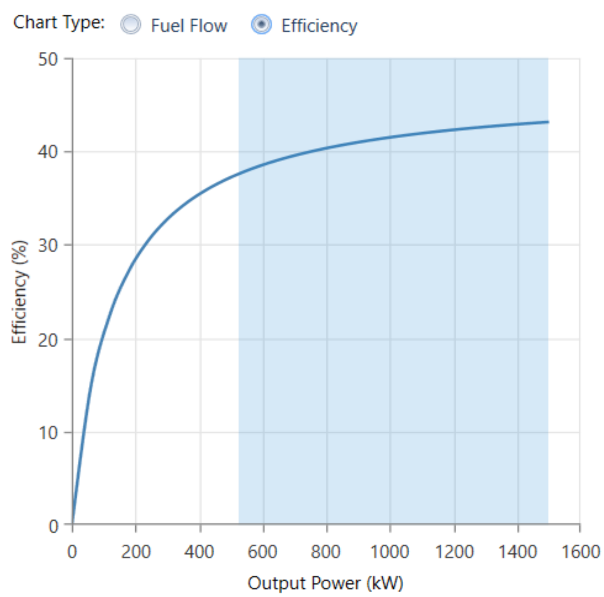

Figure 10: Efficiency graph of Natural gas generator used. [18]

Cost of Energy (COE)

The cost of energy refers to the amount of money required to produce or consume a certain amount of energy. This can include the cost of fuel, electricity, or other sources of energy needed to power equipment, vehicles, or buildings. The cost of energy can be a significant factor in the profitability of businesses and industries that rely heavily on energy consumption, such as manufacturing, transportation, and construction. It is also an important consideration for households and individuals who need to manage their energy consumption and expenses. Factors that can affect the cost of energy include supply and demand, government policies and regulations, technological advancements, and market competition. The following equation is used by the program to determine the levelized cost of energy (COE), which is the ratio of production costs to the total amount of power served:

$$COE=\frac{C_{ann,tot}-c_{boiler}H_{served}}{E_{served}} \quad (3)$$

Sensitivity Analysis

Sensitivity analysis is a technique used to assess how changes in certain variables or assumptions can affect the outcome of a particular scenario or model. In the context of energy cost, sensitivity analysis can be used to evaluate the impact of various factors on the overall cost of energy. For example, sensitivity analysis could be used to determine how changes in fuel prices, government subsidies, or energy efficiency measures could affect the cost of energy for a particular business or household. By conducting sensitivity analysis, stakeholders can better understand the risks and opportunities associated with their energy consumption and make more informed decisions about how to manage their energy costs.

In this consider we have performed affectability examination of Nominal Discount Rate (NDR). The nominal discount rate is the intrigued rate utilized to calculate the display esteem of future cash streams. It is regularly utilized in budgetary investigation to decide the net present value (NPV) of a extend or speculation. The nominal rebate rate incorporates both the genuine intrigued rate and the anticipated expansion rate. It is vital to utilize an suitable ostensible markdown rate when assessing the money related reasonability of a microgrid extend.

Within the setting of HOMER Pro, a computer program utilized for planning microgrids, the nominal discount rate is one of the inputs required to calculate the levelized cost of energy (LCOE) for a microgrid. The LCOE could be a metric that speaks to the normal taken a toll of creating power over the lifetime of the microgrid, considering all the capital and working costs, as well as the anticipated income from offering power.

The nominal discount rate used in HOMER Pro can be customized based on the user's preference or based on the prevailing market conditions. For example, if the user expects inflation to be high in the future, they may choose a higher nominal discount rate to account for the expected erosion of purchasing power. Alternatively, if the user has a low tolerance for risk, they may choose a lower nominal discount rate to reflect their preference for stability and predictability. In this study, keeping in mind about the inflation rate of future, we will be increasing nominal discount rate by 2%. The initial NDR as taken by HOMER pro was 8%, we will take it to 14% by adding 2% in each case.

RESULTS AND DISCUSSION

As mentioned above, we have used two different scenarios. In first scenario we have taken Diesel generator and in the other scenario we have taken generator which runs on Natural gas. To compare these two generators, we have taken the type of generator which have same capacity i.e. 1500 KW. After simulation is done we have got the following results.

Electrical Results

In addition to the cost summary, Homer Pro also provides detailed electrical results for a microgrid project. This contains data on each system component's energy output and consumption, as well as

the overall energy balance. Users can use this information to optimize the sizing and placement of components in the microgrid, as well as to identify areas where energy efficiency improvements can be made. They can also evaluate the impact of different scenarios, such as changes in load or renewable energy sources, on the overall performance of the microgrid. The electrical results in Homer Pro are essential for designing and operating an efficient and reliable microgrid that satisfies the community's energy requirements.

The above Figures 11 and Figure 12 represent two different scenarios used in the study, which show the electricity production of two generators when the grid is not working. With the help of the chart, we can clearly see that the natural gas Generator is generating a slightly higher amount of electricity, i.e., 856564 kwh/yr, as compared to the electricity produced by the Diesel generator, i.e., 840413 kwh/yr.

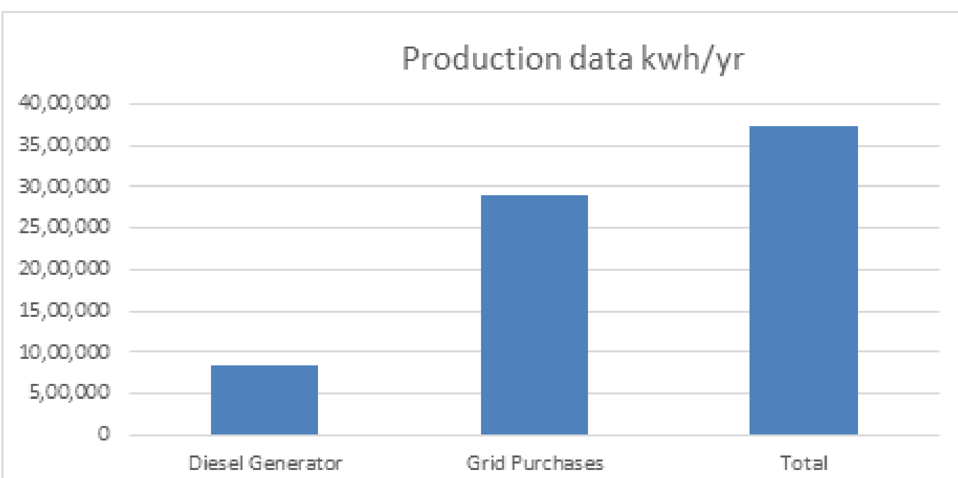

Figure 11: Electricity production data of Diesel Generator.

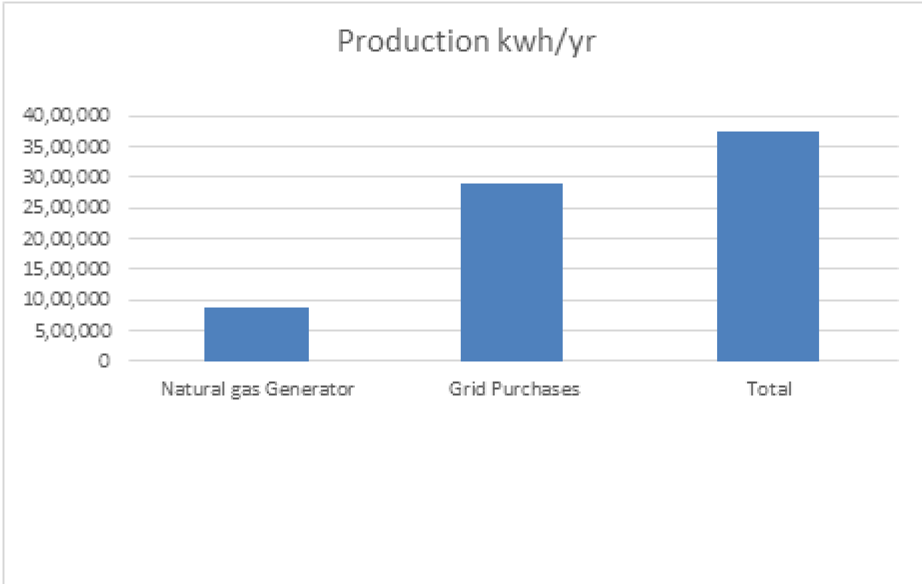

Figure 12: Electricity production data of Natural gas generator.

Time Series Plot

HOMER Pro is a software utilized for planning and analyzing microgrids. It also has a feature for creating time series plots, which are graphical representations of data over time. In HOMER Pro, a time series plot can be created by importing or inputting time-stamped data into the software. The plot can then be customized by selecting the variables to be displayed, adjusting the time scale, and adding labels and annotations. Time series plots are useful for visualizing trends, patterns, and fluctuations in data over time, which can help in understanding and predicting future behaviour.

Time series graph is a graph which shows the consumption of electricity in different time periods. So, by doing this it helps us to understand the demand of electricity in various time periods. It also helps to find the peak of consumption of electricity and also the time period where electricity demand is low. In this project we are making time series graph to analyse the variation of consumption of electricity. To analyse plot, we have taken 2 random days from peak and non-peak month i.e. July and October. July (where peak demand of electricity is observed) and October (where least demand of electricity is observed). Figure 13 and Figure 14 indicates time series plot of Diesel generator for 2 days, one from peak month and other one from non-peak month. In Figure, the orange line indicates Diesel generator power output, blue line indicates grid purchase and black line indicates total electrical load served. Through this we can see that the generator is operating only when grid electricity is not provided to the institution i.e. from 1100hrs to 1300hrs. Also, we can see that peak is coming in the month of July whereas energy consumption is moderate in month of October.

Figure 15 and Figure 16 indicates time series plot of Natural gas generator for 2 days, one from peak month and other one from non-peak month. In Figure, the orange line indicates Natural gas generator power output, blue line indicates grid purchase and black line indicates total electrical load served. Through this we can see that the generator is operating only when grid electricity is not provided to the institution from provider i.e. from 1100hrs to 1300hrs. Also, we can see that peak is coming in the month of July whereas energy consumption is moderate in month of October.

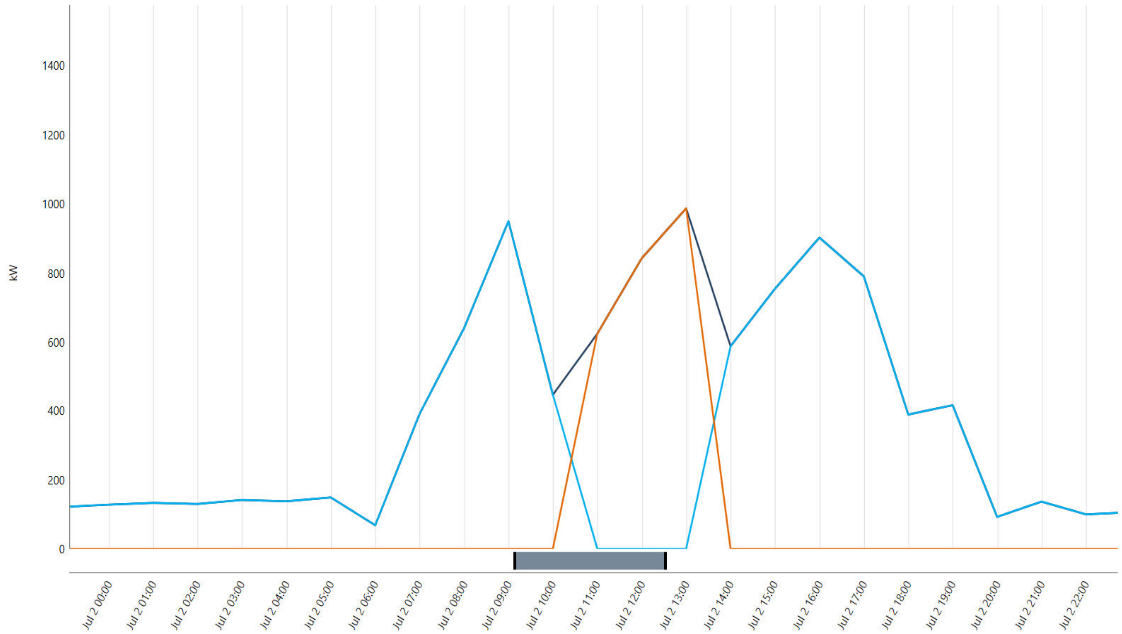

Figure 13. Time series plot of Diesel generator for a day of July. [18]

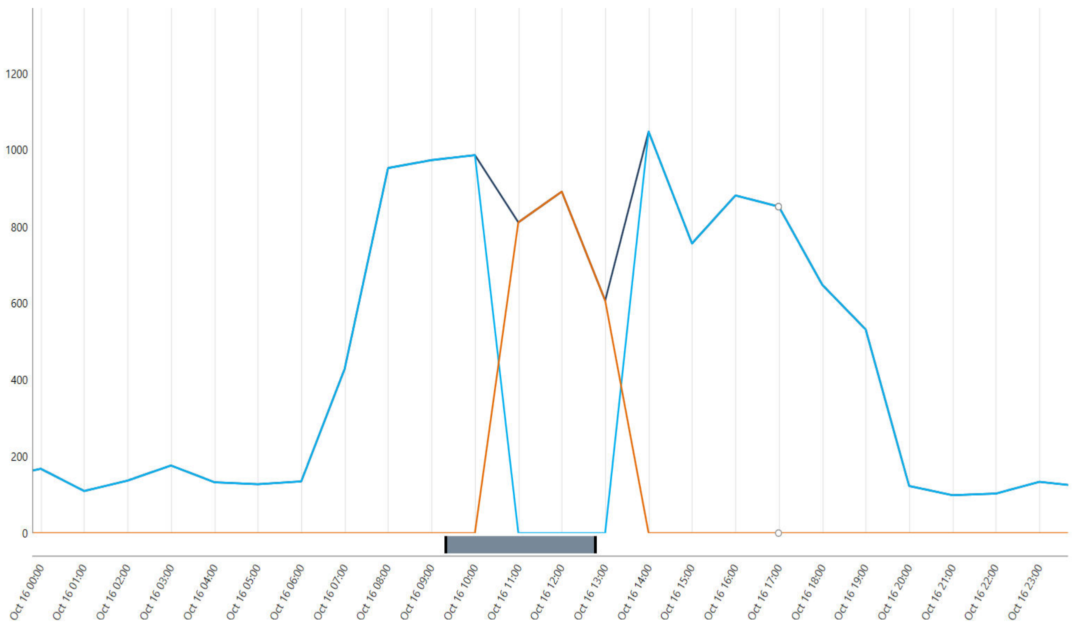

Figure 14. Time series plot of Diesel generator for a day of October. [18]

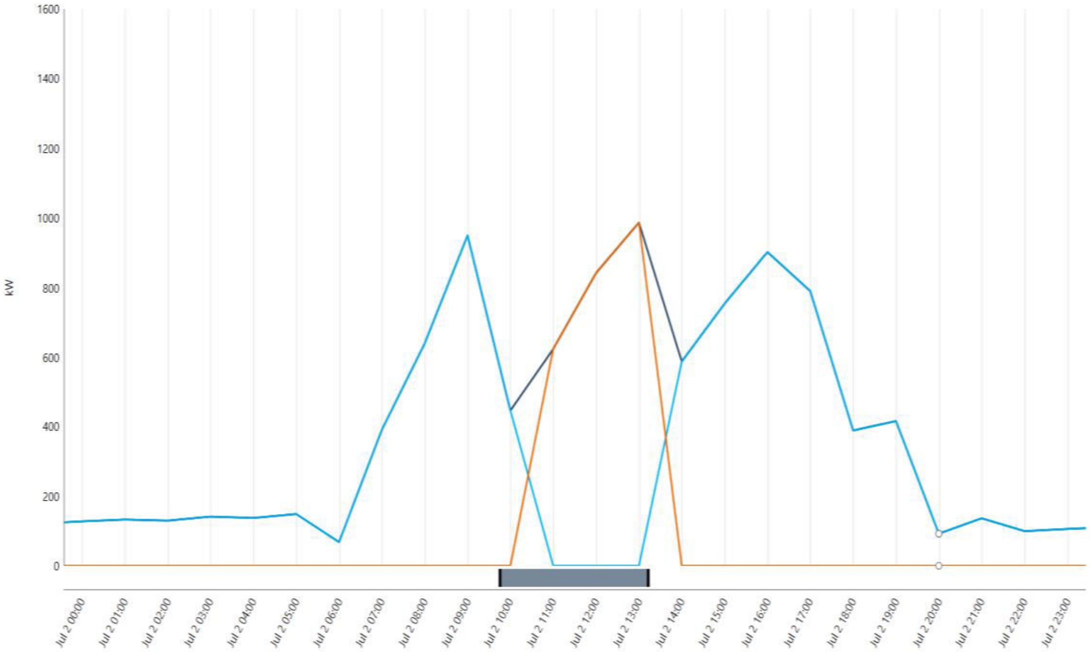

Figure 15. Time series plot of Natural gas generator for a day of July. [18]

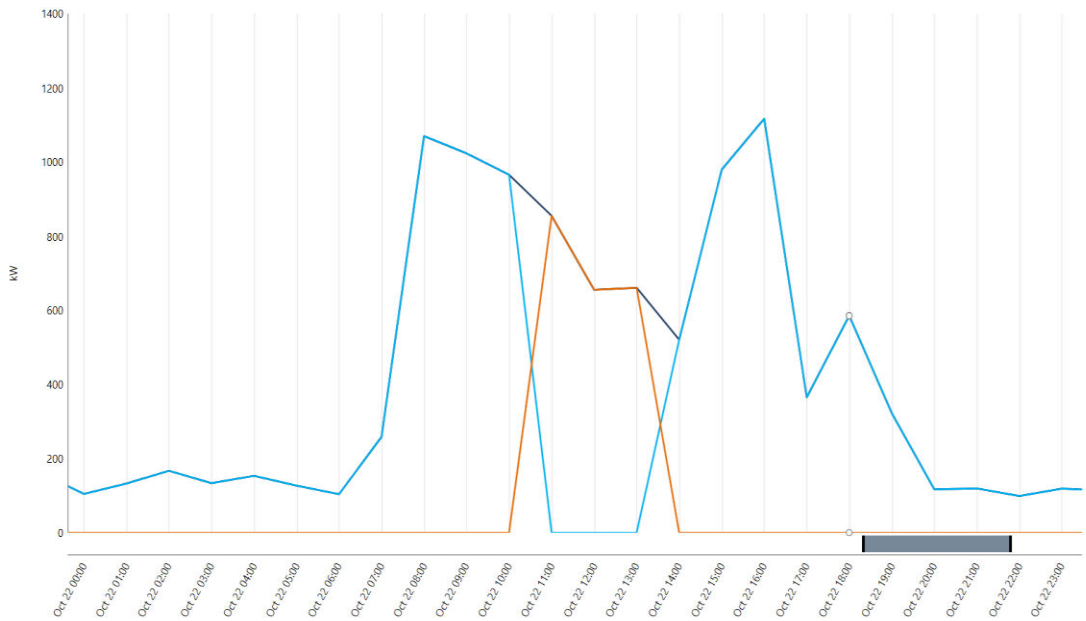

Figure 16. Time series plot of Natural gas generator for a day of October. [18]

Cost Summary

The cost summary in HOMER Pro provides a detailed breakdown of the various expenses associated with a microgrid project. It includes initial capital costs, annual operating costs, fuel costs, and maintenance costs. It also provides information on the revenue generated by selling electricity and any incentives or subsidies received. Using the cost summary, users can evaluate the financial feasibility of a microgrid project by comparing the total costs to the revenue generated. They can also identify areas where they can reduce costs or increase revenue to improve the project's profitability.

The above Figure 17 and Figure 18 represent two different scenarios used in the study, which show the cost summary of two generators. The presented results are coming from HOMER Pro in the results section. The cost summary for Diesel Generator is USD $10181093.5, and the cost summary of Natural gas Generator is USD $5561496.77. The operating and upkeep costs of Diesel generator and Natural gas generator are USD $1415.56 and USD $707.78 respectively, which is approximately half of Diesel generator. From the above results, we can clearly see that using a natural gas Generator can reduce our cost summary by approximately 50%, which is an outstanding number for generating profit.

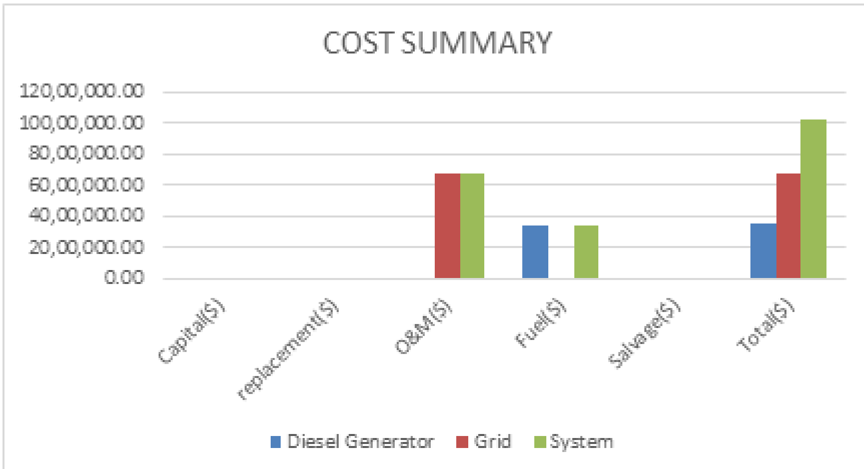

Figure 17. Cost summary of Diesel generator.

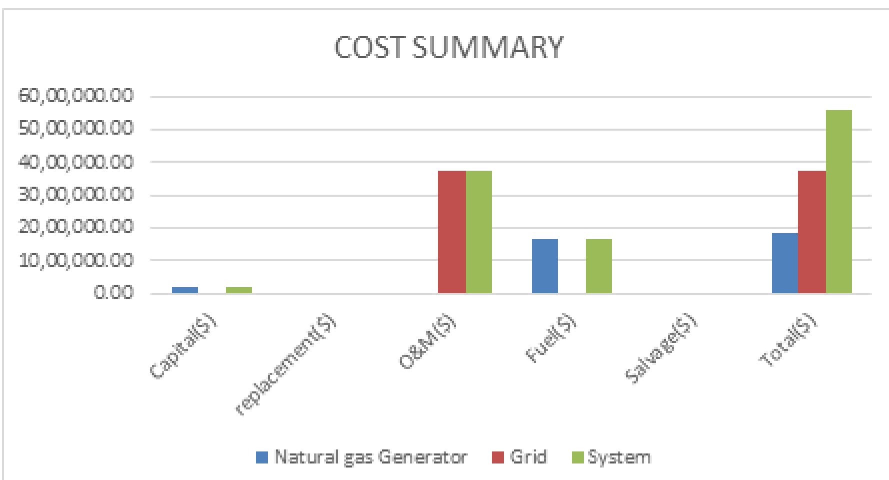

Figure 18. Cost summary of Natural gas Generator.

Fuel summary

Homer Pro provides a fuel summary that includes information on the fuel consumption and cost for each component in the microgrid system. This allows users to evaluate the financial and environmental effect of different fuel sources and to optimize the use of renewable energy sources. The fuel outline too makes a difference client to recognize zones where fuel effectiveness advancements can be made, reducing the overall cost and environmental impact of the microgrid.

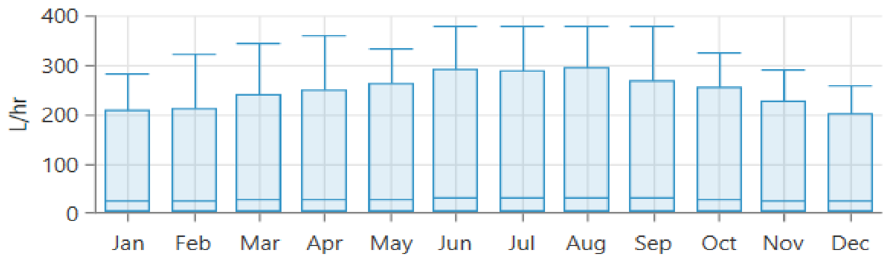

Figure 19. Monthly fuel consumption data of Diesel generator. [18]

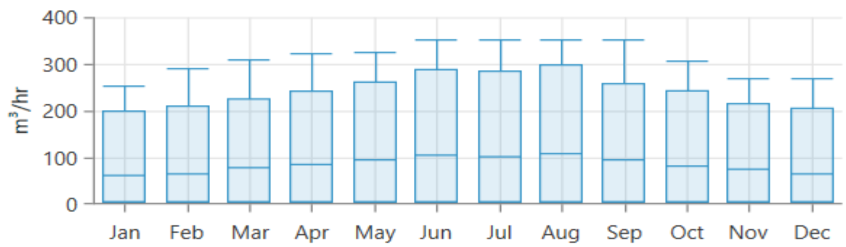

Figure 20. Monthly fuel consumption data of Natural gas Generator. [18]

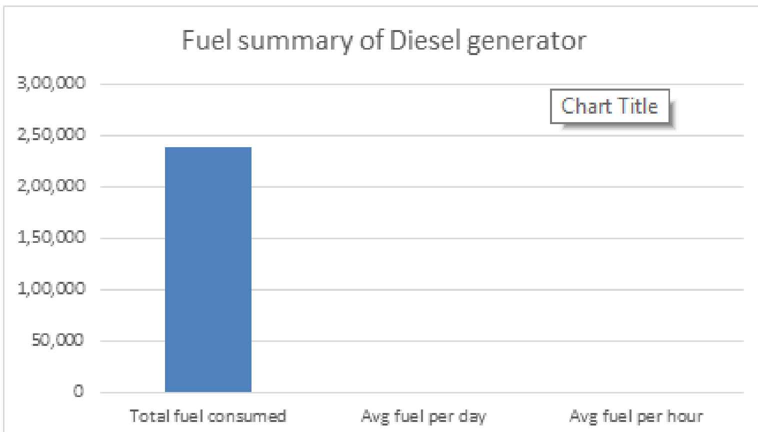

Figure 21. Fuel summary of Diesel generator.

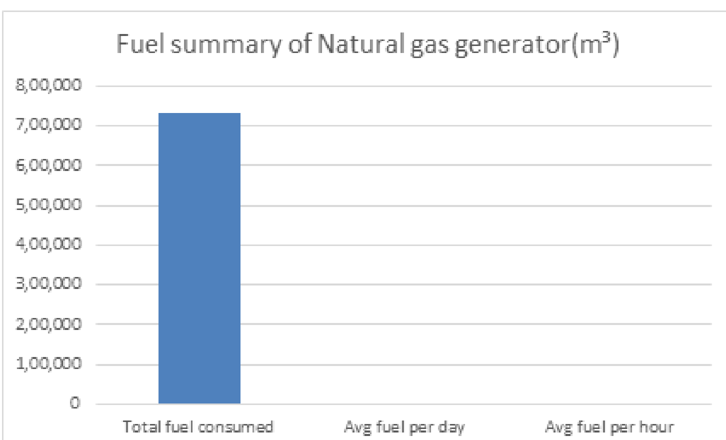

Figure 22. Fuel summary of Natural gas generator.

As we will see from the above information that natural gas generators consume more fuel than Diesel generators since natural gas incorporates a lower energy thickness than Diesel fuel. This implies that more natural gas is required to deliver the same sum of vitality as Diesel fuel. In any case, natural gas is cheaper than Diesel fuel, so it can still be a cost-effective alternative [22]. Too, the particular fuel utilization and cruel electrical proficiency of Diesel generators are 0.284 L/KWh and 35.8%, individually. Whereas the specific fuel utilization and cruel electrical proficiency of natural gas generators are 0.252 m^3/KWh and 40.1%, individually. From this information, we can conclude that the productivity of natural gas generators is higher than that of Diesel generators.

Environmental analysis

In the world of generators, environmental analysis has become a crucial aspect that institutions must consider to ensure their operations are sustainable and eco-friendly. As generators play a significant role in power generation, it is essential to understand their impact on the environment and take necessary steps to minimize any negative effects. Through environmental analysis, institutions can identify opportunities for innovation and sustainability, stay compliant with regulations, and meet consumer demand for eco-friendly products and services. governments are implementing regulations and policies to address environmental concerns, and businesses that fail to comply may face legal and financial consequences. Environmental analysis can also provide opportunities for innovation and cost savings. By identifying areas where environmental impacts can be reduced, institutions can develop new products and processes that are more sustainable and efficient. This can lead to cost savings through reduced resource use and waste generation.

In conclusion, environmental analysis is a crucial step in ensuring that products and services are developed and delivered in a way that minimizes their impact on the environment. It provides valuable information for institutions to develop strategies to reduce negative impacts and identify opportunities for innovation and cost savings.

The above Table 2 and Table 3 represent Emission caused by Diesel and Natural gas Generators Respectively. We can see that Diesel gas generator is emitting dangerous gases like Carbon Monoxide, unburned hydrocarbons, particulate matter, sulphur dioxide, nitrogen oxides in a high quantity which has been proved fatal for environment as well as for earthly lives.

Table 2: Emission caused by Diesel generator (Kg/yr).

Carbon dioxide	Unburned Hydrocarbons	Particulate matter	Sulphur dioxide	Nitrogen oxides	Carbon monoxide
245428	62	62	9473	7198	432

Table 3: Emission caused by Natural Gas generator (Kg/yr).

Carbon dioxide	Unburned Hydrocarbons	Particulate matter	Sulphur dioxide	Nitrogen oxides	Carbon monoxide
1959215	0	0	2342	1456	0

Through table 3, we can see that Natural gas generator is not emitting the dangerous gases like CO, SO_2, NO_X etc. But there is a condition for emitting criteria i.e. Natural gas generator will not emit these dangerous gases when it is running with proper service and maintenance.

Thus the, natural gas generators emit much less pollutants than Diesel generators. They emit fewer greenhouse gases, particulate matter, and other pollutants that are harmful to the environment and human health. Natural gas is a renewable energy source that's plenteous and broadly accessible. It can be created from natural squander, landfill gas, and biogas from rural and mechanical squander. It is for the most part less costly than Diesel fuel, making it a more cost-effective alternative for power generation. This can lead to lower operating costs and reduced energy bills. Natural gas generators have a smaller carbon footprint than Diesel generators. This means that they produce less carbon dioxide, which is a major contributor to climate change. Using natural gas as a fuel source reduces the environmental impact of power generation. It helps to reduce air pollution, water pollution, and other forms of environmental degradation. Natural gas generators are generally more efficient than Diesel generators. They require less fuel to generate the same amount of power, which can lead to significant cost savings over time. Natural gas generators tend to operate more quietly than Diesel generators, which can be an important consideration in urban or residential areas where noise pollution is a concern.

Sensitivity Analysis of Nominal Discount Rate (NDR)

The nominal discount rate used in HOMER Pro can be customized based on the user's preference or based on the prevailing market conditions. For example, if the user expects inflation to be high in the future, they may choose a lower nominal discount rate to account for the expected erosion of purchasing power. Alternatively, if the user has a low tolerance for risk, they may choose a higher nominal discount rate to reflect their preference for stability and predictability. In this study, keeping in mind about the inflation rate of future, we have kept nominal discount rate (NDR) between 8% to 12%. In which, we will analyse results if we do incrementation by 2% in each case.

From the above Figure 23 and Figure 24. We can conclude that, at NDR = 8%, the cost summary of a Diesel generator and a natural gas Generator is USD $3464213.66 and USD $1829611.67 respectively. From the above data, we can see that, at NDR = 8%, the natural gas generator's cost summary is approximately half that of a Diesel generator. Similarly, as we move on to NDR = 12%, the cost summary of Diesel generator and Natural gas Generator is USD $ 2508951.05 and USD $ 1363400.48 respectively. through this we can see that cost summary of Natural gas generator is nearly 45% lower than the cost summary of Diesel generator in each case. So, we can conclude with the above data that, when the inflation rate increases or NDR decreases, the use of Natural gas Generator would be very much beneficial at any point of time.

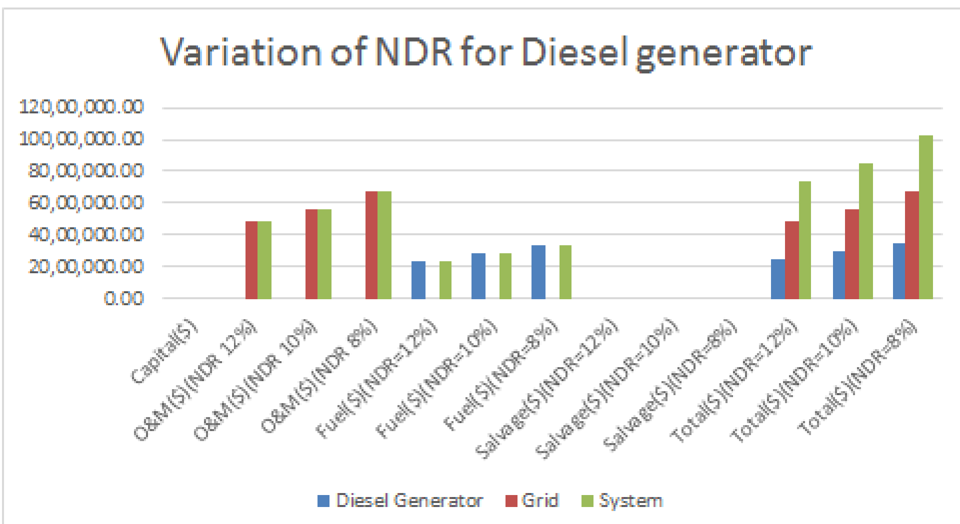

Figure 23. Cost summary of Diesel generator when NDR=12%, 10% and 8%.

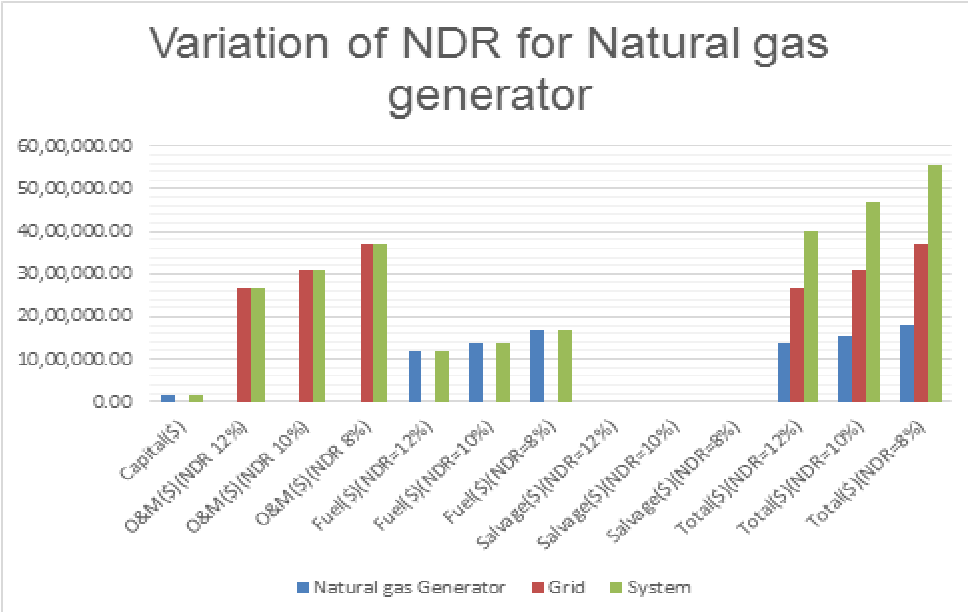

Figure 24. Cost summary of Natural gas generator when NDR=12%, 10% and 8%.

Sensitivity Analysis of Fuel Price Variation

Sensitivity analysis is used to assess how trends in fuel prices will affect the system's cost and efficiency. Sensitivity analysis can be used to assess the effect of changes in fuel costs on the cost and execution of the framework. This paper focuses on sensitivity analysis of fuel price of Diesel and natural gas in HOMER Pro, a powerful software tool for analysing renewable energy systems. Diesel and natural gas are commonly used as backup fuels in renewable energy systems. The prices of these fuels can fluctuate significantly, which can impact the economic viability of renewable energy projects. Therefore, it is important to perform sensitivity analysis of fuel price in HOMER Pro to evaluate the impact of changes in fuel prices on the cost and performance of the system. Using the sensitivity analysis tool in HOMER Pro, users can vary the fuel prices of Diesel and natural gas and evaluate the impact on the system's cost and performance. This allows them to identify the most cost-effective fuel prices for their renewable energy system and optimize its performance. By performing sensitivity analysis of fuel price in HOMER Pro, researchers can gain valuable insights into the economic viability of renewable energy projects and develop strategies for minimizing their reliance on fossil fuels.

Data of Table 4 and Table 5 are fetched from HOMER Pro under the section of sensitivity analysis of fuel price. Table 6 indicates Diesel price variation, in which we can see that, at Diesel fuel price = 1.09($/L), which is the present rate of Diesel as fuel. NPC is 10.2$, COE is 0.115($/kwh) and operating cost is 7,78,325($/yr). And is gradually increasing with increase in price of Diesel fuel. But if we see NPC, COE and operating cost for natural gas = 0.6($/m3), we can clearly examine that the NPC, COE and operating cost for using natural gas generator is approximately 43.37%, 43.54%, 44.56% respectively lesser than Diesel generator. Moreover, the operating cost of natural gas generator is also coming low when we compare its maximum fuel price to minimum fuel price of Diesel.

Table 4: Diesel price variation effecting other components.

Diesel fuel cost($/yr)	Net Present Cost NPC($)	Cost of Energy COE ($/kWh)	Operating price($/L)
1.09	10.2	0.211	7,78,325
1.3	10.8	0.225	8,28,385
1.5	11.4	0.238	8,76,061

Table 5: Natural gas price variation effecting other components.

Natural gas cost($/yr)	Net Present Cost NPC($)	Cost of Energy COE ($/kWh)	Operating price($/m^3)
0.6	5.56	0.115	4,16,282
0.8	6.12	0.127	4,59,418
1.0	6.68	0.139	5,02,554

CONCLUSION

This research investigated the viability of changing the present Diesel generator system at Delhi Technological University in Delhi, INDIA, to a natural gas generator system during grid power outages. For individual models of Diesel and natural gas generators, equal load has been provided for the analysis. HOMER Pro calculated different aspects like COE, NPC, O&M, cost summary, electrical analysis, fuel summary and emission. Total cost summary of natural gas generator is almost half of Diesel generator. By observing the results, we can conclude that the NPC, COE and operating cost for using natural gas generator is approximately 43.37%, 43.54%, 44.56% respectively lesser than Diesel generator. Natural gas generator emits less amount of dangerous gases like CO_2, unburned hydrocarbons, particulate matter, SO_2, NO_x etc. compared to Diesel gas generator high emissions. From the analysis it is observed that Diesel gas generator emits about 2454282 (kg/yr.) of CO_2, but natural gas generator emits only 1959215 (kg/yrs.) of CO_2 i.e. 20.17% lesser. Furthermore, a Diesel generator emits 9473 (kg/yd) of NO_X, but a natural gas generator emits just 1456 (kg/yd) i.e. 84.63% lesser when properly maintained. Furthermore, we can observe that the natural gas generator emits far fewer harmful gases than the Diesel generator. Natural gas generator runs at high efficiency as compared to Diesel generator for same capacity. There is no doubt that natural gas has a higher energy equivalent to Diesel per unit. which implies that less fuel is required to create the same sum of vitality. Additionally, natural gas generators have a higher power-to-weight ratio than Diesel generators, meaning that they can produce more power for their size and weight. This translates into lower fuel consumption and lower emissions, making natural gas generators a more environmentally friendly option. However, the efficiency of both types of generators depends on several factors such as the load, operating conditions, and maintenance practices. From past 5-6 years there is an emission issue caused by Diesel generators, which required alternatives for the same during grid power shortages. And natural gas generator is one of the most excellent alternatives as it emanates less destructive gasses as compared to Diesel generator, makes a difference in decreasing Delhi's air contamination.

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