Simulation of a diesel generator - battery energy system for domestic applications at Pulau Tuba, Langkawi, Malaysia

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Abstract. Design of micropower system that able to fulfil electrical energy demand is challenging due several factors, thus comprehensive and reliable simulation of such system is essential. This paper focuses on simulation of a diesel generator – battery energy system for domestic applications by using HOMER software. The simulation is based on electric load demand for 10 houses in Pulau Tuba, Langkawi, Malaysia. The simulation shows that the total cost of the energy (COE) of the system is $179,363 with more than half of it is due to the fuel cost. This system is enough to fulfill the load demand, and the battery could sustain the load independently for about 23.5 hours. Pollutant produces of the system is estimated to be as high as 32,874 kg of carbon dioxide emitted annually. These values would serve as baseline reference to compare the renewable energy systems subjected to the same electric load demands.

Keywords: diesel – battery energy system; simulation; domestic application; HOMER

1. Introduction
Micropower system is a system that generate electricity to serve a nearby load, by utilizing various types of energy generation and storage technologies [1]. Most of the micropower system has been designed and developed to satisfy the energy demands of communities beyond the reach of national electricity grid due to geographic and financial constraints. The design of micropower system is challenging due to high level of uncertainty in key parameters, for instance load size and fuel price, thus a comprehensive and reliable simulation of such system is essential to predict its feasibility and practicality. This paper is focusing on simulation of a conventional diesel generator - battery energy system for domestic applications at Pulau Tuba, Langkawi, Malaysia.

2. Simulation of Energy System Using HOMER Software
Simulation process determines how a certain system configuration, (i.e mixture of system components of different sizes, as well as an operational strategy that describes how those components working together) would perform in a given setting over a long period of time. HOMER Micropower Optimization Model was developed by the United States’ National Renewable Energy Laboratory (NREL) as a tool to design micropower systems as well as to assist in comparing various power generation technologies and applications [2]. HOMER notably enables engineers to compare and consider various design options based on their technical and economic performances.
Simulation process in HOMER serves two main purposes. The first objective of the simulation is to determine whether a specified system is feasible. In exchange for the system to be feasible, it should be able to adequately fulfill the electric loads, including to be able to satisfy all the constraints set by the modeller. Another purpose of the simulation is to determine the life-cycle cost of the system, which somewhat the total cost of overall system installation and operation over its lifespan.

Upon completion of the calculation for one year (i.e. 8760 hours), HOMER software will check if the system satisfies the constraints as set by the modeller, in terms of the renewable energy fraction, capacity shortage and level of pollutants emission. The software also calculates the life-cycle cost of the system based on annual fuel consumption, annual generator operating duration and expected battery lifespan.

3. Components of Diesel Generator-Battery Energy System

Diesel generator-battery system is one of the most common conventional energy systems for electrical power generation. The cycle charging dispatch strategy is typically be used for such system whereby the diesel generator runs at full power and subsequently charged the battery. The currency used in this research is United States Dollar with currency exchange rate of 4 Malaysian Ringgit to 1 US Dollar.

3.1. System Overview

In this research, diesel generator is used to generate alternating current electricity to fulfil the electric load. Above and beyond the electric load demand, the electricity generated is transformed into direct current electricity and stored in the battery. Similarly, when the diesel generator is not running, the battery, together with the inverter, are used instead to satisfy the electric load until it depleted to a specified discharge level. Figure 1 shows the system layout of diesel generator-battery system.

![Figure 1. System layout of diesel-battery system](image)

3.2. Electric load

Proper determination of energy load is crucial in any energy system since it will dictate the type of equipment to be used, the complexity of the system, and the overall cost of the system. Load variation throughout the day needs to be taken into consideration and the system requires to be designed based on maximum load for any month of the year to ensure sufficiency and no power shortages.

The electric load used throughout this research is based on average hourly electric demands for 10 houses in Pulau Tuba, Langkawi. In this case, the scale annual average of the load is given as 84 kWh/day and the scale peak load are 14.0 kW. Daily as well as hourly noises are given as 15% and 20%, respectively [2]. Hourly load profile is provided in Figure 2. Based on the figure, the load demand is shown to be the highest at late evening and early night, with spikes around sunrise and afternoon [3-4].
3.3. Diesel Generator
Diesel generators with unit rated capacity of 1 kW has been chosen as conventional alternating current (AC) prime mover. Its expected lifetime approximately around 15,000 hours and its capital and replacement costs are both $500 per unit. The cost for operation and maintenance is estimated at $0.05/hour [5]. The efficiency of diesel generators is depending on their output, with optimized efficiency of 30% obtained at full load. Emission factors of the diesel generator for every litre of diesel are given as 6.5 g of carbon monoxide, 0.72 g of unburned hydrocarbons, 0.49 g of particulate matter, and 58 g of nitrogen oxides.

3.4. Surrette 6CS25P Battery
Surrette 6CS25P battery with rated voltage of 6V, nominal capacity 1,156 ampere-hour, and lifetime throughput of 9,645 kWh was picked as energy storage. Battery banks of two batteries per string was used to provide 12V bus. Round-trip efficiency of the battery is 80% with minimum state of charge of 40% [5]. The capital cost of the battery is $1,150 each, and its replacement cost is expected to be around $1,000 each. The battery will also require $10 per year for maintenance purposes.

3.5. Converter
In this analysis, a converter that could act as inverter as well as rectifier was used to convert direct current (DC) to alternating current and vice versa. The capital and replacement costs of the converter are $800 each, and it virtually has zero maintenance cost. Its expected lifetime is about 15 years. Efficiency of the inverter and the rectifier are both set at 90% [6].

3.6. Operation Parameters
Due to noise emissions from the diesel generator, the operating hours are somehow limited from 6.00 am to 10.00 pm every day. Beyond this specified time, the electrical load is served solely by the batteries. Dispatch strategy used in this setting is cycle charging type where the diesel generator will run at full power to fulfil the load demand as well as in charging the battery bank up to its specified state of charge, which has been set at 80% for this study.

4. Results and Analysis of Diesel Generator – Battery Energy System Simulation
This section describes some of significant results of the simulation, with emphasis on economic, technical and environment analysis of the system simulated performances.

4.1. Economic Analysis
Diesel generator-battery energy system consisted of 10 kW diesel generator, twenty Surrette S6CS25P batteries and 5 kW converter was simulated by using HOMER software. HOMER simulation calculated that the levelized cost of energy (COE) for this system was $0.511/kWh which is significantly higher than the COE tariff for domestic utilization from Tenaga Nasional Berhad’s grid connection at $0.07 to $0.20/kWh, based on the amount of monthly consumption. Despite its higher
price, off-grid system as such may become a feasible option to electrify remote and isolated areas when connection to national grid is technically no longer practical and/or excessively expensive.

Per the economic values obtained from HOMER simulation, as shown in Table 1, the total net present cost of this system is $179,363 with 56% of this cost is contributed by the diesel cost, set at $0.65 per litre, given as $100,231. With the current trend of increasing fuel price, it is expected that the overall cost of the system will increase over time. Annual operating and maintenance (O & M) costs are expected at $25,607 per year.

On the other hand, the capital cost for the system is $32,000 as compared to its replacement cost of $25,339; with major portion of the replacement cost is contributed by diesel generator since its expected life is less than four years, and it needs to be replaced several times throughout the 20-year duration of the project.

Table 1. Net present costs of diesel-battery system

| Component          | Quantity | Capital | Replacement | O&M | Fuel | Salvage | Total  |
|--------------------|----------|---------|-------------|-----|------|---------|--------|
| Diesel Generator   | 10       | 5,000   | 13,730      | 23,313 | 100,231 | -904 | 141,370 |
| Surrette 6CS25P    | 20       | 23,000  | 9,939       | 2,294 | 0    | -2,079 | 33,155 |
| Converter          | 5 kW     | 4,000   | 1,669       | 0    | 0    | -831   | 4,838  |
| System             | 32,000   | 25,339  | 25,607      | 100,231 | -3,814 | 179,363 |

4.2. Technical Analysis

Since there is only one type of generator, all the electric production is produced by diesel generator. Unmet electric load is calculated at 66.9 kWh/year while the capacity shortage is reported as 119 kWh/year. These values are within the specified 2% capacity shortage tolerance, with renewable energy fraction is 0% as expected. The diesel generator operates for 4,065 hours annually with daily start-up at 6.00 am and shut down by 10.00 pm. Its operational life is 3.69 years; thus, needing replacement approximately five times throughout the entire project duration.

The capacity factor recorded is around 42.2 %, indicating that the diesel generator only operating around two-fifth of its nominal capacity. Its electrical output is 36,928 kWh/year with mean output of 9.08 kW. Each year the diesel generator consumes 12,484 litres of diesel with specific fuel consumption calculated at 0.338 litre for every kWh of electrical energy produced, estimated at 30.1% mean electrical efficiency.

A total of 20 batteries consist of 10 parallel strings of 2 batteries each, are used in the system. The bus voltage is set at 12 V. Usable nominal capacity of the batteries is 83.8 kWh and its lifetime throughput are 192,904 kWh. The batteries can sustain the electric load demands without the diesel generator for approximately 23.5 hours, thus any maintenance or replacement work on the diesel generator should be completed within this duration to avoid any potential of energy disruption.

The state of charge of the batteries is maintained above 40% for most of the time. There are several times where the state of charge of the batteries reduces to below 50%, particularly around 12.00 at midnight to 6.00 in the morning since the batteries are discharged to sustain the load demand and the diesel generator at that moment is shut down to prevent its noise disturbing the people that live nearby.

A 5-kW converter is used in the analysis that acts as both; the inverter as well as the rectifier. The mean output of inverter and rectifier is 1.35 kW and 1.86 kW respectively, and their corresponding
capacity factor is 26.9% and 37.2%. The converter operates for 4,751 hours as inverter and 3,998 hours as rectifier in annual term.

4.3. Environmental Analysis

Table 2 lists the mass of pollutants emits by the energy system every year. Considering the project lifetime of 20 years, the quantity of pollutant emissions will be evidently substantial and may impose damaging impacts to the surroundings. Aiming to eliminate, or at least significantly reduce these harmful pollutions is one of major steps in helping to save the environment.

![Table 2. Annual rate of pollutant emissions for diesel-battery system](image)

Table 2. Annual rate of pollutant emissions for diesel-battery system

| Pollutant            | Emissions (kg/year) |
|----------------------|---------------------|
| Carbon dioxide       | 32,874              |
| Carbon monoxide      | 81.1                |
| Unburned hydrocarbons | 8.99               |
| Particulate matter   | 6.12                |
| Sulphur dioxide      | 66                  |
| Nitrogen oxides      | 724                 |

5. Conclusion

Based on the simulation results of the diesel generator – battery energy system from technical, economic and environmental considerations, the system is found to be technically feasible, expensive and polluting. While the system is considered good from technical perspective, its economic and environmental aspects could be improved further. Reduction in the overall cost of the energy system could be achieved by using renewable energies such as solar, wind and hydrogen energies. Similarly, the pollutant emissions could be substantially decrease by replacing fossil fuels such as diesel with their renewable energy alternatives.

The values obtained from this simulation would serve as baseline reference in designing the renewable energy systems for the same electric load demands to determine the technical, economic and environmental improvements over the conventional system.

References

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