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Design Optimization Of PV And WTE Integration In Electricity Supply System For Mandalay Urban Area

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Abstract

Hybrid energy systems, which combine two or more energy systems, are becoming increasingly popular due to the rise in petroleum product prices, growing CO_2 emission awareness, and advancements in renewable energy technologies. These systems are being adopted to meet the energy and electricity demands of decentralized networks. In Myanmar, some areas still face significant challenges in accessing grid-based electricity supply. In such cases, the hybrid renewable microgrid systems offer a better alternative by reducing dependency on diesel fuel and meeting energy demands in an environmentally friendly manner. To enhance the reliability of these hybrid systems, renewable sources can be integrated with diesel generators and utility grid. This integration allows hybrid systems to compensate for the intermittent nature of renewable energy sources and achieve higher overall energy efficiency. One of the main advantages of hybrid systems is their potential for energy autonomy, as they are not reliant on a single energy source. This paper introduces a novel approach for designing a grid connected hybrid system that incorporates photovoltaic, and biomass especially the municipal solid waste. The Hybrid optimization model for electrical renewable (HOMER) is a powerful optimization model that simplifies the evaluation of off-grid and grid-connected power system designs for various applications. In this paper, the grid connected hybrid renewable energy system is designed and analyze for Mandalay region.

A. Introduction

The absence of adequate access to clean and reasonably priced energy is regarded as a fundamental aspect of poverty. Progress has been made worldwide; in particular, the number of people without electricity access fell below1billion threshold for the first time in 2017. Decentralized systems led by solar photovoltaic (PV) in off-grid and mini-grid systems are the lowest-cost solution for three-quarters of the additional connections needed to provide universal electricity; specifically, grid extension is the standard in urban areas. With the declining cost of renewables, innovation, and improvement in technologies and energy efficiency, hybrid renewable systems have become an attractive, cost-effective solution at locations which are off-grid or connected with unreliable grid. This paper aims at developing a concept design and analysis of hybrid renewable systems to meet the energy demand at Mandalay region locations in energy efficient, environmentally friendly way and thereby achieve a reduction in operating cost by reducing dependency on diesel fuel. In order to achieve this objective, the paper introduces a model for energy consumption that combines solar photovoltaic (PV) and biomass (WTE) sources. The main aim is achieved by its application in optimization-based HOMER software.

B. Research Method

Hybrid power supply systems consist of different energy sources in order to have more secured supply of electrical loads with increased reliability and durability of the system. The hybrid systems take advantage on the respective strengths of the subsystems in order to mitigate the shortcomings of the individual systems. The primary advantages of the hybrid systems lie in their enhanced reliability and cost-effectiveness compared to conventional systems. This is primarily attributed to the availability of solar sources during the day and the continuous supply of WTE energy throughout the day and night.

1. System Block Diagram of Hybrid System

A hybrid power generation system typically comprises several components, as illustrated in Figure 1. These components can be succinctly summarized and described as follows.

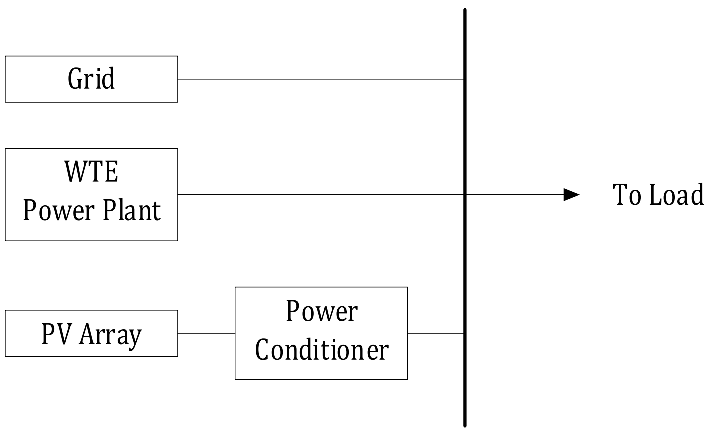

Figure 1. Illustration Of PV/WTE Hybrid System Connected With Grid

2. Advantages and Disadvantages of Homer

For the design optimization of Solar/WTE hybrid renewable energy system, Homer Pro software is used. Table 1 shows some of the merits and limitations of using the HOMER software.

Table 1. Merits and Limitations of HOMER

Merits	Limitations
Simulates a list of real technologies, as a catalogue of available technologies and components	Quality input data needed (sources)
Very detailed results for analysis and evaluation	Detailed input data (and time) needed
Determine the possible combinations of a list of different technologies and its size	An experienced criterion is needed to converge to the good solutions
It is fast to run many combinations	Homer will not guess key values or sizes if there are missed.
Results could be helpful to learn a system configuration and optimization	Could be time consuming and onerous

C. COMPONENTS OF HYBRID RENEWABLE ENERGY SYSTEM

In this research, the renewable hybrid system consists of solar photovoltaic system and waste to energy system.

1. Solar Photovolatic System

Figure 2 depicts a block diagram of a standalone PV system. The PV generator, which can be in the form of a panel or an array, serves as a semiconductor device capable of converting solar energy into direct current (DC) electricity. To cater to periods of low sunlight or adverse weather conditions, batteries are employed to store and utilize the generated power. The inclusion of batteries as a storage medium necessitates the presence of a charge controller. As the PV arrays generate DC power, an inverter is essential for converting the DC to alternating current (AC) when the PV system is connected to an AC load. The behavior of the AC electrical load within the house is determined by the requirements of the AC load.

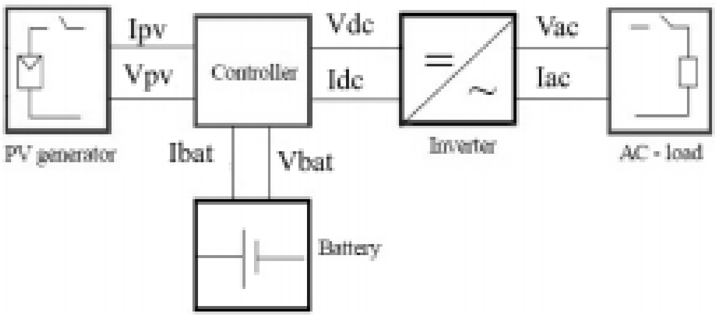

Figure 2. Block Diagram For A Typical Stand-Alone PV System

2. *Waste to Energy System*

Waste is a byproduct of human activities, including domestic, commercial, industrial, and agricultural practices. If these wastes are properly managed and utilized, they can contribute significantly to energy generation. However, if not handled appropriately, they can have detrimental effects on living conditions. Municipal solid waste, for example, consists of various materials such as glass, paper, plastic, and food waste, among other organic materials. These materials can be converted into bio-energy through different methods. The most commonly employed methods for waste-to-energy conversion are incineration, biomethanation/anaerobic digestion, and gasification. Incineration involves the burning of solid waste, which can reduce its mass by 70% and volume by 90%. This process not only helps in waste reduction but also produces steam that can be used for electricity and cogeneration purposes. Biomethanation or anaerobic digestion is an environmentally friendly energy conversion process that utilizes microorganisms to decompose biomass and produce biogas. This biogas can be utilized for combined heat and power generation. On the other hand, gasification involves the partial combustion of shredded waste to generate biogas. Certain types of solid waste, such as agricultural produce, wood, and plastics, can be gasified without any pre-treatment. The producer gas obtained from this process can be used for energy production. In conclusion, waste management and utilization play a crucial role in energy generation. By employing methods like incineration, biomethanation, and gasification, we can harness the potential of waste and contribute to sustainable energy production.

3. *Current MSW Methodology*

The primary collection of waste is carried out by private sweepers who go from door to door. In addition, waste is also collected through community bins and containers, as well as road sweeping. The streets are swept by sweepers and sanitary workers. These workers gather the collected waste into small heaps, which are then manually or mechanically loaded onto community containers or bins. Alternatively, the waste can be directly loaded onto solid waste transportation vehicles for transportation to the disposal site. Currently, Mandalay Civil Development Committee (MCDC) utilizes vehicles and equipment for the transportation of solid waste.

Figure 3. MSW Methodology Used In Mandalay City

4. *Solid Waste Generation*

Classification of solid waste are municipal solid waste (MSW),industrial solid waste (ISW), and healthcare solid waste (HSW). The increase in solid waste production has been attributed to the population growth, the expansion of trade and the increased number of industries. According to the Cleansing Department of the MCDC, current municipal solid waste (MSW) generation in the city stands about 940 tonnes per day with the per capita waste generation of 0.64kg/person/day. The population of Mandalay was 167493 in 1950, which represent a changing of 2.62% per annual. The rate of generated waste become high by more than population growth and then it has created many environmental impacts. Rate of increase of solid waste generated 3.8 times from 2005 (260 tons per day) to 2017 (922 tons per day) and this is expected to reach 2892 ton per day at 2030.

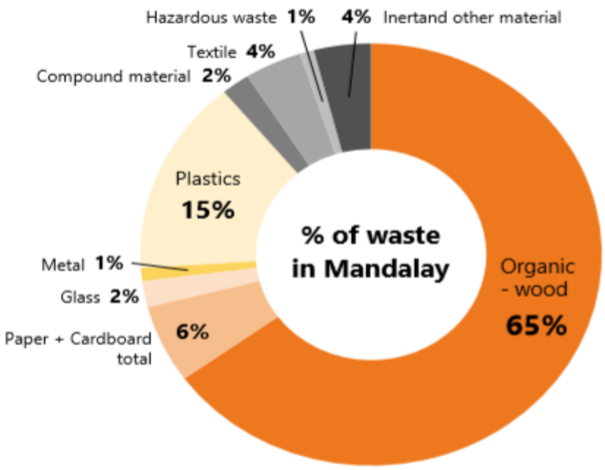

Figure 4. Waste Characterists Of Mandalay City

D. OPTIMIZATION ALGORITHM

HOMER offers two optimization algorithms, namely the derivative-free algorithm and the search algorithm. When designing a system, users may face challenges in determining the appropriate sizing or capacity for components that are compatible with the system. In the case of the derivative-free algorithm, the software will automatically select the optimal sizing to minimize the overall system cost. On the other hand, the search algorithm will simulate various system configurations based on the defined search space. The input value for the search space depends on the peak load measurement. The selected size may fall within the upper or lower range of the search space. The software utilizes several evaluation indices, including net present cost (NPC), levelized cost of energy (COE), operating cost, and renewable fraction. NPC represents the life cycle cost of a component, which is the present value of all costs associated with establishing and operating the component throughout the project's lifetime. This value is then subtracted from the present value of all revenues earned over the project's lifetime, as illustrated in the following equation.

$$C_{NPC} = C_p - C_R \quad (1)$$

where C_P and C_R are the present values of all costs and revenues earned over the project lifetime, respectively.

The algorithm takes into account various costs such as capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of purchasing power from the grid. On the other hand, revenue includes salvage value and income from selling power back to the grid. The net present cost (NPC) serves as the primary economic output in HOMER, which is utilized to rank different system configurations in the optimization results. NPC forms the foundation for calculating the total annualized cost and the levelized cost of energy (COE).

$$COE = \frac{C_{ann,tot} - C_{boiler} H_{served}}{E_{served}} \quad (2)$$

where $C_{ann,tot}$ is the total annualized cost of the system [USD/yr], C_{boiler} is the boiler marginal cost [USD/kWh], H_{served} and E_{served} are the total thermal and electrical loads served [kWh/yr], respectively. In order to determine the operational expenses of the system, Equation (5) is employed.

$$C_{operating} = C_{ann,tot} - C_{ann,capital} \quad (3)$$

Where $C_{ann,capital}$ is the total annualized capital cost [USD/yr]. In order to ensure an effective system, it is strongly advised to incorporate Renewable Energy Sources (RESs) into the architectural design. The term "renewable fraction" within the software pertains to the proportion of energy provided to the loads that originates from RESs. This can be determined by utilizing the subsequent equation:

$$f_{ren} = 1 - \frac{E_{nonren} - H_{nonren}}{E_{served} - H_{served}} \quad (4)$$

Where E_{nonren} is nonrenewable electrical production [kWh/yr], Hnonren is nonrenewable thermal production [kWh/yr].

The aim of the optimization problem is to reduce the cost of operations, as outlined below.

Objective function:

$$\min(C_{total}) = \sum P_{grid}C_{grid} + P_{gen}C_{gen} + P_{WT}C_{WT} + P_{PV}C_{PV} + P_{bat}C_{bat} + P_{con}C_{con} \quad (4)$$

The cost of each component encompasses various factors, including capital cost, operation expenses, maintenance fees, replacement charges, and fuel costs. These elements contribute to the overall cost calculation for each component.

$$C_{element} = \sum C_{capital} + C_{O\&M} + C_{replacement} + C_{fuel} \quad (5)$$

The power balance constraint between generation and demand, as well as the percentage of renewable energy, imposes a limitation on the objective function.

$$P_{grid} + P_{gen} + P_{WT} + P_{PV} + P_{bat} + P_{can} \geq P_{Load}$$
$$P_{WT} + P_{PV} \geq 60\% \quad (6)$$

E. CASE STUDY AREA

The Shwe Sar Yan substation is considering the implementation of a photovoltaic (PV) based electricity power supply. This strategic decision is made due to the proximity of the PV system to the substation, resulting in reduced losses and eliminating the need for new transmission and distribution infrastructure. Similarly, the Myauk Pyin substation is considering the establishment of a Waste-to-Energy (WtE) power plant, which is conveniently located near the substation.

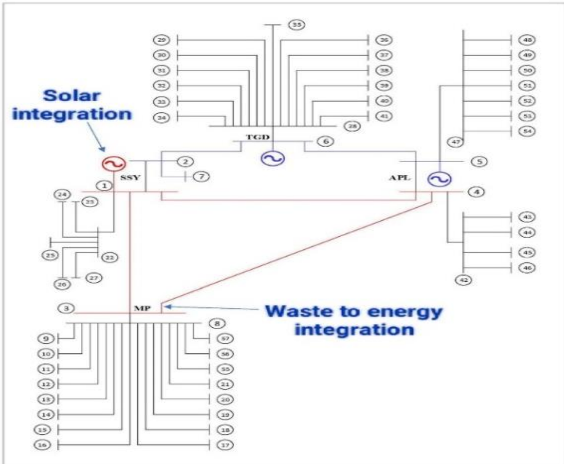

Figure 5. Target Location For Renewable Integration In The System

Shwe Sar Yan substation is situated southeast of the Buddhish temple pagoda, and east of University of Pharmacy, Mandalay. Solar integration supply system is closely located Shwe Sar Yan substation. This area is wide.

Figure 6. Case Study Area

In the north, Kyar Ni Kan Landfill is 17.17 km from the city center and is 12.4 acres wide. The dumpsite receives approximately 550 tons of solid waste per day. Domestic and industrial wastes are not dumped into the landfill separately.

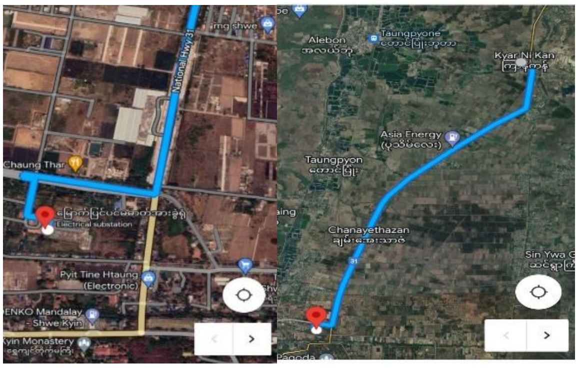

Figure 7. Case Study Area

This thesis is intended for sustainable electricity distribution of township under MESC power supply consisting of 7 townships. Currently the maximum demanded of this distribution system is about 692MW.

F. MODELING OF SYSTEM FOR DESIGN OPTIMIZATION USING HOMERPRO SOFTWARE

The concept of a hybrid energy system pertains to the utilization of multiple energy conversion devices in tandem to fulfill an energy requirement. These systems find application in both isolated and grid-connected scenarios, and typically incorporate at least one renewable energy source within their configuration. Hybrid energy systems serve as an alternative to conventional systems, which predominantly rely on a single fossil fuel source. A hybrid solar and waste to energy power generation system encompasses a PV module, waste to energy technology, a generator, a solar regulator, and a converter. Figure 7 illustrates a schematic diagram of the proposed hybrid system. The PV module and waste to energy technology collaborate harmoniously to meet the demand for power.

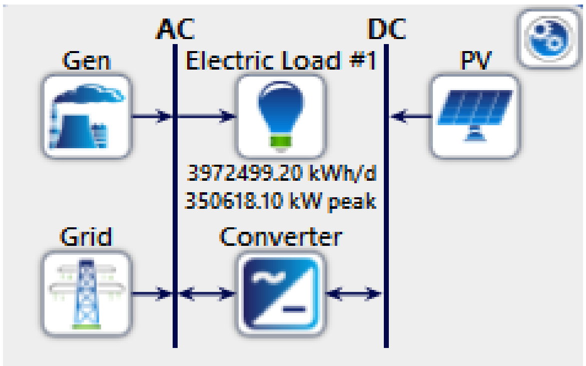

Figure 8. Hybrid System Configurations

G. SIMULATION RESULT AND ANALYSIS

The HOMER software employs iterative processes to achieve the most favorable outcome for each selection sensitivity variable in the hybrid renewable energy system. In this analysis, HOMER provides micro-optimization models of a grid connected hybrid energy system based on different design parameters such as initial investment, NPC, COE, consumption of energy/fuel, and environmental sustainability. By varying those factors HOMER software generates different system combinations of power sources as shown in Table 2. From Table 2, hybrid grid connected energy system has estimated initial cost, operating and maintenance cost, and NPC of $887M, $102M, and $2.21B respectively, with the corresponding cost of energy $0.115.

Table2. HOMER Optimization Result

	Component	PV+WTE+Grid
	PV (kW)	297938
	Gen (kW)	390000
	Grid (kW)	999999
	Converter (kW)	213658
Cost	NPC ($)	$2.21B
	COE ($)	$0.12
	Operating Cost($/yr)	$102M
	Initial Cost ($)	$887M
System	Ren frac (%)	30.1
	Total Fuel (L/yr)	153798336
Gen	Hours	2939
	Production (kWh)	580504064
	Fuel (L)	153798336
	O&M Cost ($/yr)	3438630
	Fuel Cost ($/yr)	46139500
PV	Capital Cost ($)	744843776
	Production (kWh)	481103584
Converter	Rectifier Mean Output (kW)	0
	Inverter Mean Output (kW)	51198
Grid	Energy Purchased (kWh)	461294144
	Energy Sold (kWh)	40329528

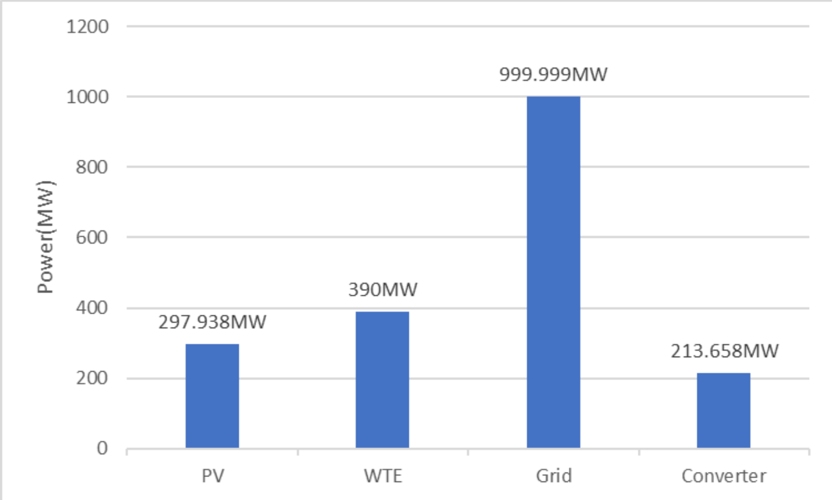

Figure 9. Amount Of Energy Generated For Selected Area

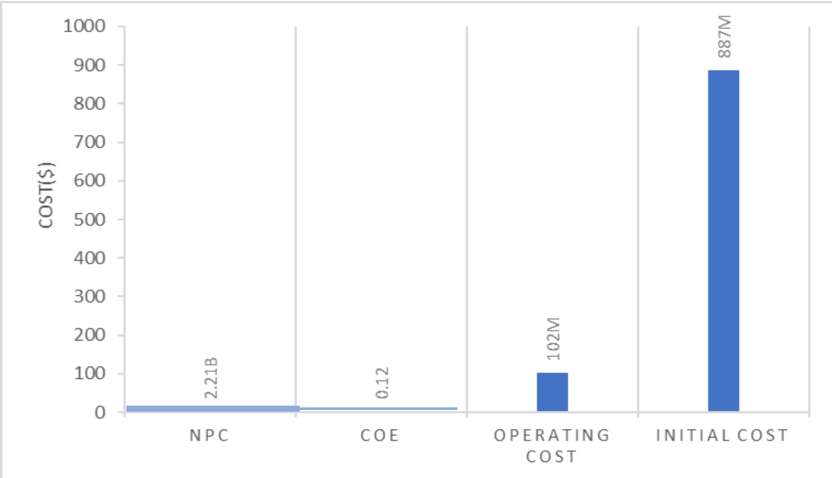

Figure 10. Total Cost Of PV, WTE And Grid For Selected Area

H. CONCLUSION

In this study, the optimization of hybrid renewable energy resources including solar PV and waste to energy based grid-connected system for Mandalay city is modelled and sized using HOMER Pro software. There are several parameters taken into consideration when proposing such system for the city. The various types of loads are modelled depending on a total load of Mandalay city of 397249.2 kWh per day is determined. Homer Pro is used to optimize the size of hybrid system components for solar PV, and waste to energy power plant. The simulation results obtained indicate that the grid-connected hybrid renewable energy system is capable of powering the total estimated load of the city and serve as an appropriate optimized solution to the energy need of Mandalay city. The result express that the hybrid system with 297.938MW PV panels, 390MW waste to energy and 213.658 MW power converter is the most economically feasible option for Mandalay urban area.

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