Feasibility Analysis of Stand Alone Renewable Energy System in Remote Islands by using HOMER

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Abstract: This paper aims to conduct a feasibility study on a remote village or town in any remote located islands, where a micro or mini off grid solar system can be installed. The study involves a detailed calculation on energy load modelling necessary to set up an off-grid system. It considers various parameters and limitations, such as: weather conditions, solar angles, financial constraints, and government aid. With finite data and tangible assumptions, this study is done on HOMER energy and it will potentially provide the hypothesis to set up a real-world off-grid system.

***IndexTerms* - Feasibility Study, HOMER, Off-grid, Renewable Energy.**

I. INTRODUCTION

Without the provision of modern energy and electricity there is no support for socio-economic development and improvement of the living conditions in rural areas in developing countries. Although the awareness of the importance of reliable electricity infrastructure is given there are still about 20% of the global populations who have no access to electricity. So, the analysis of how successfully a remote electrification project can be completed, accounting for factors that affect it such as economic, technological, legal and scheduling factors is the need of the hour. [1]-[6]

The study focuses on a small island upon the Hội An river in the Duy Vinh district, Quang Nam Province, Vietnam. The island has about 50 buildings in total with 48 acres dedicated to agriculture while the rest is barren land. We also assume there is a small hospital on the island as well. This island is an ideal option for our study as it is isolated and has the potential of putting up a large off-grid system with no human hazards. Furthermore, almost a quarter of the total population in rural area of Vietnam have no electricity [7]. The goal is to utilize the available land to set up an off-grid system by analyzing the energy load requirement for the agricultural land and possibly for the neighboring towns in the district. Based on the load requirement, barren land area, and financial budget, three likely scenarios are proposed and a mini or micro off grid system is projected.

The primary objective is to study the different types of energy loads in the area. As half of the island is used for agriculture, the energy load required for the island in full/itself is minimal. The rest of the island can be used to put up PV panels and energy storage units. Due to inadequate data on the different energy loads used in this area, we assume average load consumption per home/building for our calculation. Considering the financial budget, load requirements and other area specific constraints, a micro off-grid system is proposed. The location of the island is 15°50'56.6"N 108°20'48.6"E.

According to an energy analysis by Energypedia, roughly 15,000 small scale PV off-grid applications with a total capacity of 3,600 kW, were installed in Viet Nam by the end of 2014 [8]. Larger Off-grid systems, including hybrid systems are also being implemented. The average maximum and minimum temperatures of the location are 34 °C and 23 °C respectively. [9]. The solar radiation is around 4-4.5 kWh/m2/day. Quang Nam also has good sun hours all through the year. The wind speed is about 7mph on an average all through year [10]. With its monsoon climate and impedimental International grants, wind energy appears unfavorable in Vietnam.

II. LOAD MODELLING

Energy load analysis is vital to design an off-grid system. Since batteries are used for the energy storage, it is important to calculate the voltage and amp hours of every load that needs to be powered by the off-grid system. There are different types of energy loads that consume voltage and current in different levels and time intervals.

1. *Residential Load*

The various residential loads in the island are assumed based on the per capita income of the country. Since it is a rural island and the rate of living is low, we consider loads for solar home systems (SHS) that would be ideal for the site. The unit cost of electricity is $0.08 for Quang Nam province. Based on these assumptions, we can estimate a feasible amount that sums to about 6% of the total income that an individual need to pay for electricity. The total residential load required is calculated from various types of appliances connected on daily basis as shown in the table I.

Residential Load				
Type of Load	**Watts (W)**	**No. of Appliances**	**Usage Hours**	**Load (kWh)**
Light Bulb	30	5	7	1.05
Fan	75	2	12	1.8
T.V	100	1	5	0.5
Cell Phone/Charger	15	1	3	0.05
Fridge	300	1	24	7.2
Water Heater (Immersion Rod)	1000	1	1	1
Total Connected Load per house (kW)				1.72
Total Residential Load (kW)				85.75
Total Energy required (kWh) per house			**Per day**	10.6
			Per month	317.85
			Per Year	3868
No. of Houses				50
Total Residential Energy required (MWh)			**Per day**	0.5298
			Per month	15.9
			Per year	193.359

Table I: Residential Load Calculation

2. Commercial Load

We assume that there are 10 commercial buildings in the island. Furthermore, we also assume a small hospital for medical emergencies and a rice mill. The commercial building includes all the lighting loads used in the residential load as well as a few additional appliances. The total commercial load required is calculated from several types of building as shown in Table II.

COMMERCIAL LOAD					
Type of Buildings	Type of Load	Watts (W)	No. of Appliances	Usage (Hours)	Load (kWh)
Hospital	Light Bulb	50	7	7	2.45
	Fan	75	5	10	3.75
	Fridge - Meds	200	1	24	4.8
	Nebulizer	100	4	3	1.2
	Incubator	450	4	7	12.6
	Computers	150	2	10	3
	Number of Hospitals			1	
	Total Connected Load for Hospital (kW)			3.43	
Commercial Buildings	Type of Load	Watts (W)	No. of Appliances	Usage (Hours)	Load (kWh)
	Light Bulb	50	10	8	4
	Fan	75	7	9	4.7
	Computers	150	5	8	6.0
	Number of Commercial Buildings			10	
	Total Connected Load for Commercial Buildings (kW)			17.75	
Rice Mill	Type of Load	Power (kW)	No. of Appliances	Usage (Hours)	Load (kWh)
	Paddy Cleaner	0.76	1	5	3.8
	Husker	5.5	1	5	27.5
	Number of Rice Mills			1	
	Total Connected Load for Rice Mill (kW)			6.26	

Table II: Commercial Load Calculation

3. Agricultural Load

The irrigation lands constitute about 40acres in total. These fields should maintain around 4-inch (0.33 ft.) level of water. Consequently, continuous access to a water source is essential as water consumption is high. A 2HP permanent irrigation pump with a flow-rate of 3950 gal/hour for 10 ft. is ideal for this scenario as it matches with the load and energy requirement. The total agricultural load required is modelled from the data of land area, Pump specifications and operation time as shown in Table III.

4. Total Energy load for the Island

Final Calculations		
Total Connected Load of Island (kW)		149
Total Energy (MWh)	Per Day	1.07
	Per Month	32
	Per Year	391.3

Table IV: Load Calculations Summary

Agricultural Load		
Area of each agricultural land (acres)		1
No. of lands		40
Total area of lands (acres)		40
Pump Capacity (HP)		2
Q = d(inches) x A (acres) / t (hrs)		3950
Depth of each field (inch)		4
Area of each field (acres)		1.2
Reqd Flow Rate per day (gal/hr)		3950
Drawdown Head (H_{dd}) (ft)		5
Static Head (Hs) (ft)		5
Total Head (H) (ft)		10
Operation time (hrs)		4.5
Energy Reqd per acre (kWh)		7
Total Connected Load for Water Pumps (kW)		60
Total Agricultural Energy Reqd (MWh)	**Per day**	0.34
	Per month	10.2
	Per Year	124.1

Table III: Agricultural Load Calculation

III. ENERGY RESOURCES FOR SELECTED AREA

Energy resource is a significant factor in an Off-grid system. Every part of the world has different energy resources, some being abundant and some meager. The type and profundity of resources available in an area determines the design and construction of an off-grid system. While solar energy is becoming a universal renewable energy resource after wind energy, relying on just one type of resource is a handicap to any off-grid system. It is important to consider all possible sources of renewable energy sources available. Since there is no apt data available for Duy Vinh island, data are collected from neighboring locations. For this site, three likely, energy resources are taken into consideration.

1. Solar Energy:

Solar Energy is a renewable energy source from the sun. For any Photovoltaic (PV) system, an average, annual, effective, and continuous sun hours are necessary. These data are computed and stored by weather stations across the world. The average sunlight data is taken from Danang, a location about 21 miles away from the island. The annual average sun light hours and peak sun hours are 105.8 hours and 5.8 hours respectively. A peak sun-hour, specifically, is an hour during which the intensity of sunlight is 1,000 watts per square meter.

Month	Peak Sun Hours
Jan	4.4
Feb	5.1
Mar	3.4
Apr	6.9
May	8.3
Jun	7.9
Jul	8.3
Aug	6.7
Sep	5.8
Oct	4.7
Nov	4
Dec	3.6
Annual	5.8

Table V: Peak sun hours for Quang Nam

Fig 1: Average Peak Sun hours for Danang

*2. **Wind Energy**:*

Wind energy is generated from wind turbines. Like solar panels, wind turbines are dependent on wind to generate electricity. As the project is based on a conservative economy, only a small-scale turbine can be used. Since the island has a tropical monsoon season, the average wind speed, doesn't meet the minimum requirement of small scale turbine. Furthermore, there is substantial risk of turbine collapsing as it is on an island. The average wind speed is 5.6mph, collected from Quang Nam province weather data [11].

Month	Avg Wind Speed (mph)
Jan	5.6
Feb	4.7
Mar	6
Apr	5.8
May	6.5
Jun	6.7
Jul	7.6
Aug	5.1
Sep	4.3
Oct	5.6
Nov	5.1
Dec	4.7
Annual	**5.6**

Table VI: Average wind speed(mph) for Quang Nam

Fig. 2: Average wind speed(mph) for Quang Nam

3. Fuel Energy:

Any Off-grid system is reliant on renewable resources which is contrary to its purpose as renewable resources itself is unreliable and is limited by time and weather. In cases like such, when resources fail to provide energy, a backup energy source is highly essential. In this scenario, diesel generators are connected to the system as a backup resource. Since diesel is nonrenewable source, its function is limited in the entire system. The average price of diesel in Vietnam for the month of Feb 2017 is $0.64 per liter. [12]

IV. SYSTEM DESIGN

System is sized based on the load requirement and various time schedules used. It explains the several types of components used for the site and its functions. The design also describes the electrical background of the system. For convenient accessibility, the system and battery bank are located in the center of the island. 1 autonomy day is considered as rainfall does not exceed 50mm for any two consecutive days.

Component	Rating	Manufacturer	Count
Solar Panel	275W	Canadian Solar	1131
Inverters	100 kW	Princeton	3
Charge Controller	480 A, 750V	East Group	45
Batteries	38.6Ah, 350V	Tesla	45
Diesel Genset	20 kW	Generac	3

Table VII: System Components

1. PV System

Based on the required load analysis, a 312kW system which generates 400Mwh per annum is projected. Helioscope tool is used to design and calculate the row spacing according to the orientation of the panels. The production of the system is maximum during March - August. The PV system design details are as per table VIII.

Orientation of the panels is considered close to the latitude od the location to maximize the output of the system. Considering the structural factors for the racking, the portrait orientation seems suitable for keeping it low cost and effective. As for the landscape, the weight increases as more modules can be fit in. Also from maintenance perspective, it would be lot easier to manage fewer panels per table for the ground mount.

2. Generator

Diesel generators are used as a backup source if the system fails to generate enough energy to meet the loads. Taking the cost of diesel into account and the fact that it is a nonrenewable source of energy, three 20kW generators are considered for the system. The capital cost and maintenance of the generator is high, so it is only connected to the agricultural load with limited run time of 4 hours.

3. Battery

The battery is selected such that the charge controller withstands the branch voltage. According to the recommended list of batteries for the site from Homer software, Tesla Powerwall 2.0 seems to fit the requirement. Due to financial constraints, the batteries are connected only to the residential load. 45, 38.6Ah batteries are used to power the system. The battery has a 100% Depth of Discharge with high efficiency. Since the battery bank is located near to the PV panels, line losses are reduced.

PV system details	
Tilt Angle	15 °
Altitude Angle for Duy Vinh	46.5 °
Azimuth	180 °
Orientation	Portrait
Row Spacing	7 ft

Table VIII: PV system detail

Fig. 3: Helioscope PV panel layout

4. Charge Controllers

High power MPPT solar charge controller is preferred as it can withstand maximum power point voltage. East Group controller with a rating of 0-750Vc, 60A-480A is considered as the voltage and current rating is higher than the output from the PV system. (East Group) The rating of the charge controller can be found by dividing the output power of the branch with the battery voltage.

5. Inverter

Three 100 kW inverters are necessary to meet the system demands. Princeton GTIB-100 G1.2 0 is suitable for the system as a 350kW inverter costs more than three 100kW inverters together.

The system is characterized by testing the loads on maximum and minimum output. To get a better understanding, a two 24-hour load analysis is calculated by assuming all the loads are connected and run for two 24-hour period with 1 autonomy day. Two scenarios are proposed, first occurring on a sunny day to consider the maximum efficiency of the system. Second being on a cloudy day where the system generates the least energy.

The first scenario is considered on a summer solstice, with maximum sun light. Batteries are charged and discharged consecutively. The PV system produces ample energy to change the batteries and supply the loads. The generator remains off as there is no energy drop.

The second scenario is considered on a winter solstice, with minimum sun light. Batteries are discharged rapidly and almost a little or no energy is generated to recharge. The PV system therefore fails to meet the energy needs of the site and as a result the entire system depends on the generator for power.

IV. RESULTS AND DISCUSSION

HOMER Energy software is used to determine the final calculations for the off-grid system. Like Helioscope software, Homer doesn't offer customization with PV system. It considers and compares different parameters and values like, total energy output, weather conditions and cost of fuel to project a default system that would produce optimum result at low cost. Based on the load characteristics and battery performance, two scenarios are proposed.

1. Considering PV panel and Diesel Generator as a source

By connecting all the components of the system, around 40% power is generated from the diesel generator and 60% power from PV modules. Homer, by default projected a 66kW PV system. This is not feasible as the off-grid system is designed to utilize maximum power generation from PV and reduce dependency on the diesel generators. However, Homer allows 40% generator run as the cost of power generated by the diesel generator is less than power generated by the PV system. This scenario report is shown in the Fig. 4

2. Considering PV panel as an only source

Eliminating the generator from the system, results in projecting a 641Kw. Yet again, Homer considers the different parameters and proposes a 641Kw system for a total connected load of 149 Kw. This results in a bigger PV system which is not practicable for the budget.

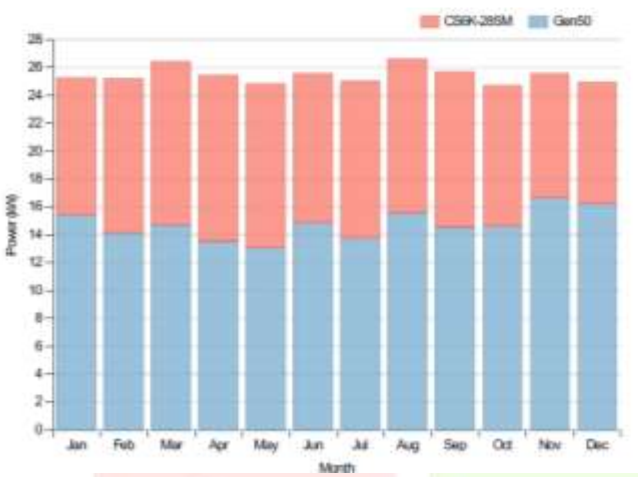

Fig. 4: Homer Report – Scenario 1

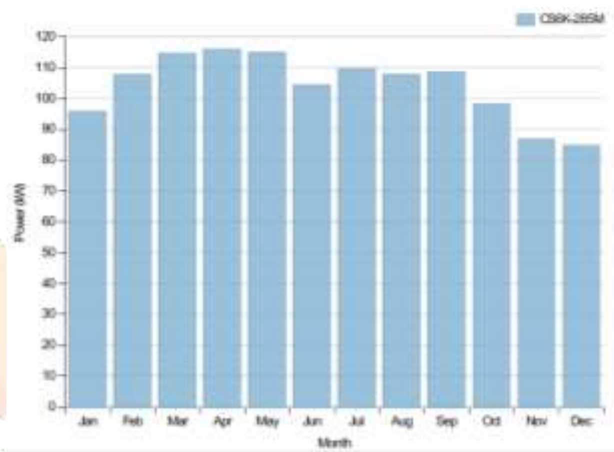

Fig. 5: Homer Report – Scenario 2

3. Cost Analysis

We have made certain assumption for the cost analysis of the project and some of them are hypothetical. As seen from the data, the PV modules contribute to the majority of the cost required for the system followed by the Tesla battery pack. We have assumed the total cost of the project would be taken as a loan and annual interest payments would be made as needed. Further inputs of the cost model are given below. Cash flow is calculated for the period of time required for the payback also with the NPC (Net Present Cost) after the loan is closed. Recommendations are given based on the cost analysis and NPC for the project in Table IX.

Component	Manufacturer & Model	Per unit/kwh Cost	Number Included	Total Component Cost
PV Module	Canadian Solar CS6K	$0.29	312 kW	$90,480.00
Batteries	Tesla Powerwall2	$4,000.00	45	$180,000.00
Charge Controller	East Group GSC336-384	$400.00	45	$18,000.00
Inverter/controller	Princeton GTIB-480-100	$31,326.00	3	$93,978.00
Genset	Generac RD02023	$8,126.00	3	$24,378.00
			Total Cost	$406,836.00

Table IX: Cost Analysis

4. Inputs for Financial Model

The diesel generated electricity costs $0.30/kWh [13] whereas the unit cost of electricity from the grid is $0.08. In Vietnam, the government provides incentives only for the systems which are less than 50kW. As our system is 312kW, we won't receive any incentives. We assumed the maintenance costs for the system would be low because the labor cost is less in Vietnam compared to the other countries. The general corporate tax rate for Vietnam is 25% and the term for the loan is considered as 25 years [14]. The central bank discount rate for Vietnam is 9% [15]. The inflation rate for Vietnam is 4.65% [16].

5. Results from Financial Model

Considering the 312kW system for the total connected load, the capital cost becomes $1,096,356. As we do not have any incentives available for Vietnam, the net installed cost remains the same. With the assumed 50 residential homes, 10 commercial buildings, hospital and a rice mill, the average cost for each individual is around $17,600 Considering the per capita income of the Vietnam, the cost required for the system is more than their income. As the system is not connected to the grid, we would not be receiving any income from the generated electricity. So, considering all the factors the payback period for total system is around 33 years.

Simple Payback (years)	**33.19**
Cash Flow	**$ 436,178.90**
NPC	**$ 318,314.97**

Table X: Cash Flow Analysis

V. CONCLUSION

We have designed the off-grid system for the remote island in Duy Vinh, Vietnam considering the island has 50 residential houses, 10 commercial buildings which includes convenience stores, a small-scale rice mill industry and a hospital for emergencies. The total connected load for the island is around 149kW. And the daily energy usage for all the building is around 1MWh per day. The off-grid system replaces the present diesel generated electricity along with the power from the connected grid. The high cost of diesel and the interrupted power supply from the Vietnam's grid are the main factors for replacing these with the off-grid system.

We have also considered the wind energy for the system, however the average wind speed for the island despite being near the sea is less than 9mph which is the minimum required speed for a commercial scale wind turbine. Hence, we have only considered Solar energy for the off-grid system. The PV module system we designed has a capacity of 312 kW which will be connected to the load along with the battery bank.

The renewable energy penetration is 93.8% for the current system. The components are selected in such way that they would help the local businesses and it would be cheaper for transport within the country. Considering the financial analysis, the payback period is around 33 years and when the total cost is distributed among each individual, the cost is more than the income received per house.

This would be more feasible if the system is designed for individual houses as the cost would be less and it can be financed by the local banks. The net installed cost increases only when we consider the system for the whole island. We can also include small scale wind turbines for individual houses who can afford them and this would also help increasing the renewable energy penetration for the island.

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