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A Study on Hybrid Renewable Energy System for Electrification in a Remote Area of Bogamati, Assam

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Abstract: *Fossil fuels contribute a lot towards carbon emissions which results in global warming and climate change. In today's scenario, sustainable development is need of the hour. In terms of electricity generation, this can be achieved by renewable energy. Due to the high variations in electricity generation due to seasonal variations,Hybrid Renewable Energy System (HRES) is need of the hour. The objective of this study is to model a Hybrid Renewable Energy Source to be installed in a remote area of Bogamati, Assam and supply electricity to a neighborhood of 100 houses. For the electricity generation, Solar Photovoltaic (PV) and Wind Turbine were chosen. The characteristics of these systems are based on weather conditions and thus they are unreliable in itself. To counter this, two types of storage were chosen – a battery bank(BAT) and a Pumped Hydro Energy Storage (PHES). The system is further added withconverter to bridge the AC and DC bus. The study was done in two sections – off-grid and on-grid. The system was optimized in HOMER Pro which is one of the best optimization software. It has been found that for the off-grid configuration, PV-BAT system is giving the least Net Present Cost (NPC) and Cost of Energy (COE) and for the on-grid configuration, PV-PHES gives the most ideal results with a possibility of selling electricity back to the grid.*
Keywords: *HOMER, Renewable Energy, Optimization, Hybrid Renewable Energy System (HRES), Solar Photovoltaic, Wind Turbine, Battery, Pumped Hydro Energy Storage (PHES)*

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I. Introduction

India is a developing country and the development can't reach to each and every family of the country if there is no proper electricity supply. To solve this problem, the Government of India has launched the Saubhagya scheme to provide energy access to all by last mile connectivity and electrical connections to all remaining un-electrified households in rural as well as urban areas to achieve universal electrification in the country.

Although the scheme was a huge success, but 24-hour electricity is not yet a reality. This can be mainly attributed to thefact that the electrical generation is yet too low to cater the demands of the entire country. The solution can be to build more electrical generation plants in the country –the most common being the Thermal Power Plants. But these come at their own cost of pollution and to fight Global Warming we need to look at alternate sources.

The renewable energy sources for e.g., Solar, Wind, Hydro, Fuel Cells, etc. can be effectively used to solve thisproblem. Renewable energies are source ofclean, inexhaustible competitive energy. They differ from fossil fuels principally in their diversity, abundance and potential foruse anywhere on the planet, but above all in that they neither produce greenhouse gasesnor polluting emissions. Their costs are alsomuch less compared to the trend of riding fuel prices.

The randomness of generated power by renewable energy sources has led the experts in this field to provide sustained and permanent load supply with Hybrid Renewable Energy Sources (HRES). This usually consists of two or more renewable energy sources used together to provideincreased system efficiency as well as greater balance in energy supply. HRES arebecoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise inpetroleum products and the pollution associated with it.

National Institute of Solar Energy (NISE) has assessed the Country's solar potential of about 748 GW assuming 3% of the waste land area to be covered by Solar PV modules. The National Institute of Wind Energy (NIWE), has installed over 800 wind-monitoring stations all over country and issued wind potential maps at 50m, 80m and 100m above ground level. The recent assessment indicates a gross wind power potential of 302 GW in the country at 100 meter above ground level.

The state of Assam hasa renewable energy potential of 14,487 megawatt (MW) with solar energy taking the largest share. Solar energy has the highest potential in the state with 13,760 MW capacity, followed by biomass with 279 MW, wind energy with 246 MW, and small hydro projects with 202 MW capacities.

Under the aegis of the PM-KUSUMscheme, Assam has set plans for the increase the renewable energy production. Under the component-A of the scheme, thestate plans to set up 50 MW of small solar power plants on barren or fallow land of farmers. Under Component-B, it aims to install 1000 standalone solar pumps, while under Component-C, solarization of 500existing grid-connected agriculture pumps is targeted.

As per the reports of the CEA the growth of renewable energy has been around 8% from the financial year 2012-17. The renewable energy generation in FY 2012-14 was 31MW, in FY 2015-16 it was 34MW and 45MW in FY 2017. The state is actively participating to meet the allocated targets of MNRE to contribute its share forthe 175 GW national target by year 2022.

HRES can be formed by the combination of multiple renewable energy sources and can be either on grid or off grid. The PV-Wind Turbine-Hydro-Battery, PV-Battery, PV-Biomass, PV-Wind Turbine-Pumped Hydro, etc. are a few examples of most commonly used HRES systems. These systems can also be connected to traditional diesel generators to meet the sudden high peak demands in case of without significantly increasing theinstallation costs and excess electricity generation. The advantages of HRES are –

- Continuous power supply
- Utilization of renewable energy in the best possible way
- Low maintenance cost
- High efficiency compared totraditional generators
- Efficient load management

However, HRES do come with itsdisadvantages which are –

- Complicated controlling process
- High installation cost
- Less battery life

In this Internship, we chose Bogamati – a remote hilly area in Assam asour study location. The area has a few residential houses and has a huge tourist potential. The goal of this study is to designa HRES to supply electricity to the households of that area. Different combinations of HRES involving horizontal axis wind turbine, solar photo voltaic (PV), Pumped Hydro Energy Storage (PHES) and battery bank have been studied. The systems have been modeled using hybrid optimization model for electric renewable HOMER software, and these are techno-economically evaluated for the existing low load factor conditions of the area.

II. Literature Review

From the study of Lawan *et al.*[1] it can be concluded that the solar PV flat platehas enormous adaptable models and if paired with the adequate alternative energy models such as PEMFC, it can potentially that could replace conventional fossil fuel system. Jahanbani *et al.*[2] concludes thatWind turbines and PV can be effectively used for HRES modelling in remote areas as the reliability is increased. This is because when there is no sun there can be wind and vice versa. This significantly reduces the load on batteries. Behera *et al.*[3]states that HRES with some storage as backup near load center change the scenario of unidirectional power flow to bidirectional with the distributed generation. The performance can be enhanced with advanced control schemes in a centralized system controller or distributed control. In grid-connected mode, these can support thegrid to tackle power quality issues, which optimize the use of the renewable resource. Arraez-Cancelliere *et al.*[4] developed an optimum methodology which prioritizes the use of renewable sources among other sources. It also allows the simulation of hybrid renewable systems and the evaluation of its economic and reliability integrated by diesel and photovoltaic generation with energy storage. It minimizes the total cost and maximizes the reliability of supply using particle swarm optimization (PSO). Khattab *et al.*[5] found that the NPC and COE is lower in case of PV only and increased by using WT with PV system due to the lower wind speed rates in the specified location. The capacity shortage percent decreased with using diesel generator in the system, although the NPC increased. Monthly average wind speeds on the location are much lower than the turbine rated wind speed which leads to non-optimal operation of the PV/WT. This leads to higher NPC and COE values. Singh*et al.*[6] has used HOMER to find the optimization analysis and an inclusive evaluation showing that the hybrid renewable energy based microgrid system encompassing photovoltaic (PV), diesel generator (DiG), battery (BAT), fuel cell (FC), wind turbine (WT) and convertor (CONV) turns out to be the best scenario for the considered area. Arefin *et al.*[7] designed and simulated a hybrid energy system and to support a small community considering an average load demand of 85 kWh/d with a peak load of 8.7 kW. The optimization and simulation are performed in HOMER and it is found that the COE of the optimized system is about USD 0.431/kWh and the NPC of the optimized system is about USD 160,626.00. The proposed hybrid energy system is economically and environmentally feasible in comparison with other conventional power generation systems and can be implemented in countries like Australia, Bangladesh, Myanmar, Indonesia, Thailand and Singapore. Okedu *et al.*[8] in his study found that the cash flow summary results demonstrates that increase load profile leads to more capital, operating, replacement, increase fuel and salvage value of the project for the wind turbine, PV, diesel and battery systems. However, the converter system was found to be independent of the load profiles.

III. Data Collection

An area with 100 household wasconsidered. An average load approval of 300KW is considered taking an average of 3KW for each house. In the Summer season, the maximum load reaches 280KWat 12:00 PM due to the use of fans, coolersand air conditioners. The consumption slowly reduces to 150KW from 1:00 PM to5:00 AM. In the winter seasons, themaximum load reaches 200KW from 7:00 PM to 10:00 PM considering the usage of electrical heater at that time. This graduallydecreases to 11:00 PM to 6:00 AM. This data is then plotted in the Yearly ElectricalLoad Data of the HOMER Pro software. The detailed graph of the plotted values is shown in Figure 1, 2 and 3.

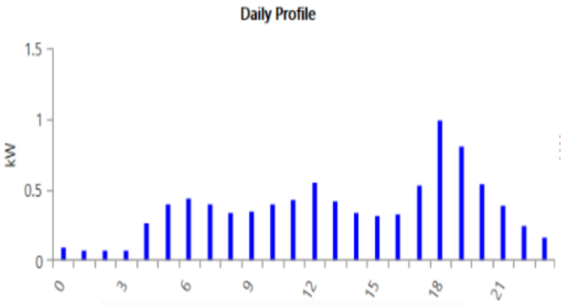

Fig 1 – Daily Electric load profile

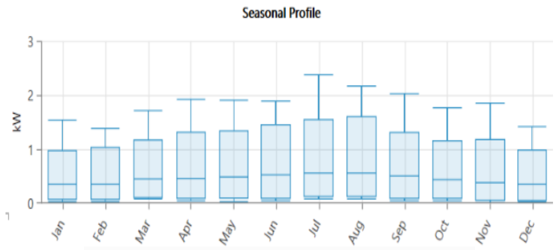

Fig 2 – Monthly electric load profile

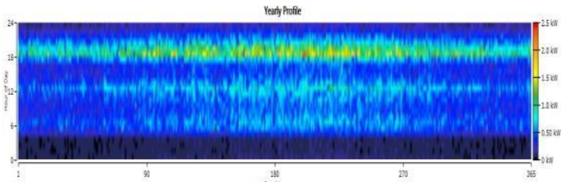

Fig 3 – Yearly electric load profile

The Solar data was taken from the National Solar Radiation Database of the National Renewable Energy Lab represented in Figure 4; the Temperature and Wind data was taken from the NASA Surface meteorology and Solar Energy labsrepresented in Figure 5 and 6. The data cannatively be inserted into the HOMER Pro software by entering the required location of the place.

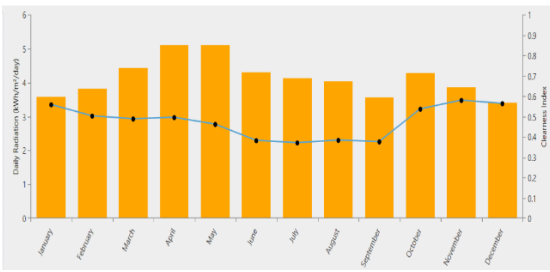

Fig 4 – Monthly Average Solar GlobalHorizontal Irradiance Data

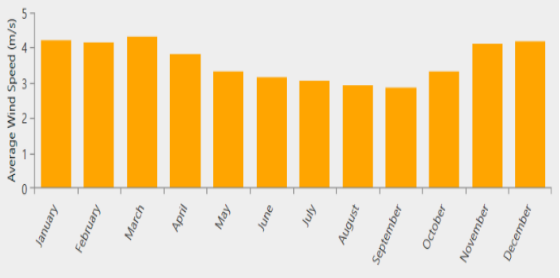

Fig 5 – Monthly Average Wind Speed Data

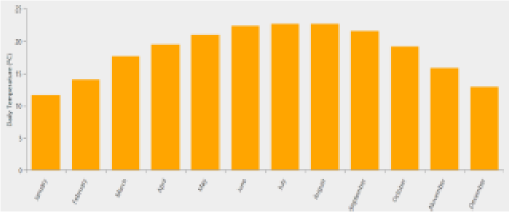

Fig 6 – Monthly Average temperature Data

Global Horizontal Irradiance (GHI) is the total solar radiation received by a horizontal surface. It is the sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI), and ground-reflected radiation. DNI is the amount of radiation received by the surface that is perpendicular to the rays that comes in straight line from the sun from its current position in the sky. DHI is the amount of radiation received by the surface that does not arrive on a direct path from the sun. HOMER uses Solar GHI to compute flat-panel PV output.

The prices of the components were taken from their respective websites and other shopping sites. As most of the components were of foreign origin, the total price is calculated in US Dollars.

4. Detailed Modelling of the HRES

The details of all the components along with the methods of cost optimization used to model the HRES is discussed below:

4.1 Photo-Voltaic module –

A solar panel or photo-voltaic module is an assembly of photo-voltaic cells mounted in a framework for installation. Solar panels use sunlight as a source of energy to generate direct current electricity. A collection of PV modules is called a PV panel and a system of panels is an array.

Power generated from a solar panel can be calculated using the relation

$$P_{pv} = A \times \eta_p \times \eta_{pc} \times P_f \times I_d \qquad (1)$$

where, A = area of the solar panel (sq. met.), η_p = efficiency of the solar panel, η_{pc} = efficiency of the power conditioning apparatus and inverter, P_f = packing factor of the solar panel, and I_d = daily irradiance.

Where the daily irradiance is given by

$$I_d = \int_0^{24} I_{sc}(t) \qquad (2)$$

where $I_{sc}(t)$ = hourly solar irradiance (W/m^2).

For this study, we have used the Sharp ND-250QCS with 60 polycrystalline silicon cells as the PV module. It is a flat plate type module with rated capacity of 250 Watts. It has a temperature coefficient of -0.4850 and an efficiency of 15.3%. The capital and replacement cost are $160 and has a lifetime of 25 years.

4.2 Wind Turbine –

A wind turbine is a device that converts the wind's kinetic energy into electrical energy. Wind turbines are manufactured in a wide range of sizes with either horizontal or vertical axes. There are also various wind turbines which can produce power in small scale manner.

The wind power output for a single wind turbine is defined as

$$P_{wind(t)} = \frac{1}{2}\rho A v^3(t) C_p \qquad (3)$$

where, ρ is the air density (in kg/m^3), A is the swept area of the rotor (in m^2), v(t) is the wind speed (in m/s), and C_p is the power coefficient of the wind turbine. Thus, energy produced by the wind turbine in a day is given by

$$E_w = \int_0^{24} P_{wind}\, dt \quad (4)$$

For this study, we have used the AWS HC 650W Wind Turbine. It has a hub height of 10m, rotor diameter of 2.2m with a rated capacity of 650 W. The capital and replacement cost are $2300, Operation and Maintenance (O&M) cost is $10/year and has a lifetime of 20 years.

4.3 Energy Storage (Battery) –

An energy storage device captures energy produced at one time for use at a later time to reduce imbalances between energy demand and energy production.

For this study we used EnerSys PowerSafe SBS 780 with a Nominal Voltage of 12V and Nominal Capacity of 10.5KWh with a 4-string size. The capital and replacement cost are $550 and has a lifetime of 15 years.

4.4 Pumped Hydro Energy Storage (PHES) –

A Pumped Hydro System builds potential energy by storing water in a reservoir at a certain height when there is excess energy. It converts the potential energy to electricity by releasing the potential energy to turn the turbine generator when there is a demand. The reservoir is located at a certain height above the turbine generator (the head height) to generate potential energy. The flow rate is the amount of water (meters cubed per second) that flows in or out. The following equation can be used to calculate the energy storage capacity of a pumped hydro system:

$$E = 9.8 \times \rho_{water} \times V_{res} \times h_{head} \times \eta \quad (5)$$

where, E is the energy stored in joules; divide by 3.6 x 106 to convert to kWh, ρ_{water} is the density of water; usually about 1000 kg/m^3. V_{res} is the volume of the reservoir in cubic meters h_{head} is the head height in meters and η is the efficiency of the energy conversion, and must consider losses like turbine efficiency, generator efficiency, and hydrodynamic losses.

The flow rate in meters cubed per second to power in kW can be converted using the following equation:

$$P = 9.81 \times \rho_{water} \times h_{head} \times \eta \times F/1000 \quad (6)$$

where, F is the flow rate in cubic meters per second.

The storage system in this example is based on the Idealized Storage Model which is a generic storage. The Generic Pumped Hydro has a reservoir that can store a capacity of 1000 m^3 of water, which can be discharged over a 12-hour period. Since the same generator/turbine act as a pump in reverse, the maximum charge and discharge current remains the same.

A 22 KW generator has been considered for this generic case. The Electricity Storage Association gives a range of costs for PHES of $500/kW to $150/kW. Accordingly, the costs can vary from $11,000 to $33,000. Taking an average of $22,000 as capital cost, $1000 for the replacement and O&M costs to be $500/year and has a lifetime of 15 years.

4.5 Converter –

Any system that contains both AC and DC elements requires a converter. It is made up of Inverter and Rectifier. The Inverter converts DC electricity to AC electricity whereas the Rectifier converts AC electricity to DC electricity.

For this study we used Fronius Symo 24.0-3 480 with a Rectifier efficiency of 98% and an Inverter efficiency of 97.50% which is parallel with the AC generator. The capital and replacement costs are $3500 with a lifetime of 10 years.

4.6 Grid –

The entire system is connected to the grid. The shortage of electricity is made up by buying from the grid whereas the surplus electricity produced can be sold back to the grid. The Grid Power Price and Grid Sellback Price is taken to be 0.100 $/kWh and 0.080 $/kWh respectively.

4.7 Cost Calculation –

The specialty of HOMER is that the cost optimization can be done with the help of multiple cost calculation methods such as total Net Present Cost (NPC), levelized Cost of Energy (COE), Operating Cost, Initial Capital Cost, etc. They are discussed in detail below –

4.7.1 Initial Capital Cost –

The initial capital cost of a component is the total installed cost of that component at the beginning of the project. Homer lists the sum of all the costs of all the components in the results.

4.7.2 Operating Cost –

The operating cost is the annualized value of all costs and revenues other than initial capital costs. HOMER uses the following equation to calculate the operating cost:

$$C_{operating} = C_{ann,\ tot} - C_{ann,\ cap} \qquad (7)$$

Where, $C_{ann,\ tot}$ is the total annualized cost (in $/year) and $C_{ann,\ cap}$ is the total annualized capital cost (in $/year).

The total annualized cost is the annualized value of the total net present cost. HOMER calculates the total annualized cost using the following equation:

$$C_{ann,\ tot} = CRF(i \times R_{proj}) \times C_{NPC,\ tot} \qquad (8)$$

where $C_{NPC,\ tot}$ is the total Net Present Cost, i is the annual discount rate, R_{proj} is the project lifetime year and CRF() is a function returning the capital recovery factor.

4.7.3 Net Present Cost –

The total net present cost (NPC) of a system is the present value of all the costs the system incurs over its lifetime, minus the present value of all the revenue it earns over its lifetime. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue. HOMER calculates the total NPC by summing the total discounted cash flows in each year of the project lifetime. The total NPC is HOMER's main economic output, the value by which it ranks all system configurations in the optimization results, and the basis from which it calculates the total annualized cost and the levelized cost of energy.

4.7.4 Levelized Cost of Energy –

HOMER defines the levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system.

The COE is calculated by dividing the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total electric load served, using the following equation:

$$COE = \frac{C_{ann.tot} - C_{boiler} H_{served}}{E_{served}} \qquad (9)$$

where, $C_{ann,\ tot}$ is the total annualized cost of the system (in $/year), C_{boiler} is the boiler marginal cost (in $/kWh), H_{served} is the total thermal load served (in $/kWh) and E_{served} is the total electrical load served.

The second term in the numerator is the portion of the annualized cost that results from serving the thermal load. In systems, such as wind or PV, that do not serve a thermal load this term is zero. The

COE is a convenient metric with which to compare systems, but HOMER does not rank systems based on COE.

5. Methodology

The simulation and optimization of the model was done in HOMER (Hybrid Optimization of Multiple Electric Renewables), Pro software. It is a microgrid software and is the global standard for optimizing microgrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. It is highly efficient in simplifying the task of evaluating designs for both off-grid and grid-connected power systems.

The advantages and disadvantages of the HOMER Pro are briefly discussed in Table 1 –

Table 1 – Advantages and disadvantages of Homer

Advantages	Disadvantages
HOMER can simulate with the help of real technologies from its list of available components in its catalogue.	Quality input data is required for each source.
Very detailed results are provided which can be used for optimum analysis and evaluation.	Detailed input data for each time and date is needed.
Determines the best combination from a list of different configurations and determines its size.	High experience and knowledge are required to convert the results to good practical solutions.
It is very fast and can run many possible combinations simultaneously.	It cannot determine the key values or sizes if they are not specified.
The results are very helpful in system configuration and optimization.	Analyzing the results can be time consuming and onerous.

The modelling was performed in two sections. In the first section, PV, WT, PHES and BAT were considered to make an off-grid system. The data from National Renewable Energy Lab and NASA Surface Meteorology and Solar Energy Lab of the location of Bogamati (26°48.4'N, 91°42.3E) was inserted in the resources section of the software. Then, the load profile as discussed in the earlier was inserted. This was further connected to the PV, WT, PHES, BAT and Converter. The WT, PV, BAT and PHES were connected to the DC bus, electric load was connected to the AC bus and the converter bridges the DC and AC bus. The schematic diagram is shown in figure 7.

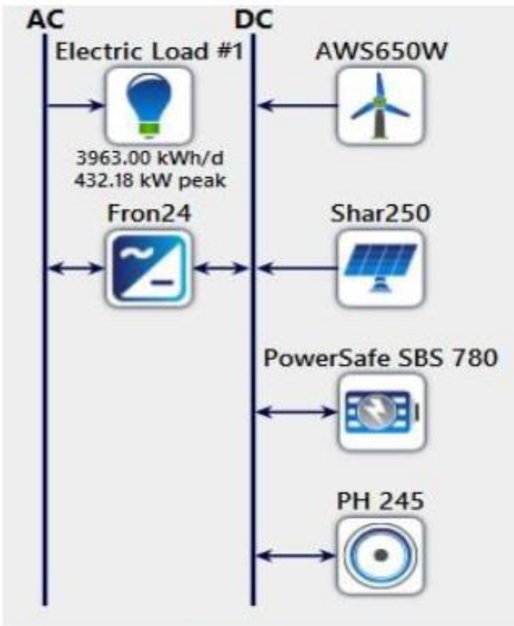

Fig 7 – Off-Grid Schematic Diagram

In the second section, the model wasconnected to a nearby grid. The excess electricity thus generated can be sold to thegrid. This will result into lesser excess electricity generation and can also handle occasional high peak demands. For this modelling a constraint of minimumrenewable fraction of 85% was considered.This means that out of the total load consumption, a minimum of 85% is to be used from the renewable sources and the rest from the grid. The mean outagefrequency i.e., the average of the grid failures per year is taken to be 12 with a repair time of 1.5 hour and a repair time variability of 0.05%. The connection is such designed that BAT and PHES charging from and discharging to sell to grid is restricted. The WT, PV, BAT and PHES were connected to the DC bus, electric load and grid were connected to theAC bus and the converter bridges the DC and AC bus. The schematic diagram is shown in figure – 8.

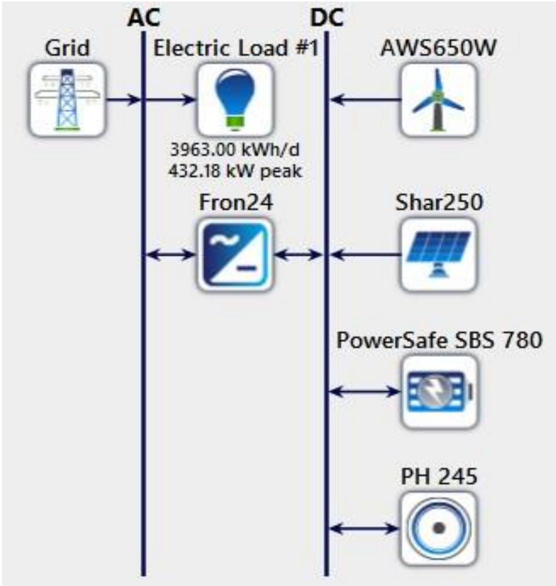

Fig 8 – On-Grid Schematic Diagram

VI. Results and Discussion

The simulation was run in HOMERPro. Table - 2 gives the optimization resultswhen the system with PV, WT, PHES, BAT and Converter was connected to the off-grid load. Table – 3 gives the electrical data of the combinations of the components.

Table 2 – Optimization results of off-grid system

System (Ranked by least NPC)	PV (kW)	WT (Nos)	BAT (Nos)	PHES (Nos)	Conv (kW)	NPC ($)	COE ($)	Operating Cost ($/year)	Initial Capital ($)
#1 PV/BAT	2769	-	1426	-	821	3.04 M	0.163	27,972	2.68 M
#2 PV/WT/BAT	3183	8	1222	-	430	3.07 M	0.164	21,890	2.79 M
#3 PV/PHES	2382	-	-	53	681	3.23 M	0.173	33,776	2.79 M
#4 PV/WT/PHES	3171	10	-	41	443	3.35 M	0.179	25,755	3.02 M
#5 WT/PHES	-	9765	-	137	871	31.0 M	1.66	419,037	25.6 M
#6 WT/BAT	-	14,633	1968	-	436	41.8 M	2.24	541,159	34.8 M

Table 3 – Electrical Data of off-grid system

System (Ranked by least NPC)	Electricity Production (kWh/year)	Electricity Consumption (kWh/year)	Excess Electricity (kWh/year)	Excess Electricity(%)	Unmet Load (kWh/year)	UnmetLoad (%)
#1 PV/BAT	3,812,868	1,445,451	2,308,662	60.5		10440.0721
#2 PV/WT/BAT	4,384,990	1,445,585	2,880,970	65.7		9100.0629
#3 PV/PHES	3,279,289	1,445,490	1,620,968	49.4		10050.0695
#4 PV/WT/PHES	4,370,120,	1,445,500	2,717,129	62.2		9950.0688
#5 WT/PHES	3,728,090	1,445,636	2,111,678	56.6		8590.0594

#6 WT/BAT	5,586,598	1,445,546	4,087,568	73.2	9490.0656

From Table – 2, it can be seen that the cost of the first system i.e., PV/BAT comes out to be the cheapest at a COE of $0.163 and Initial capital cost of $2.68M. The cost of the second system of PV/WT/BAT is also close to the former at COE of $0.164 and but comes with a higherinitial capital cost of $2.79M. The cost of the other four systems is however quiteappreciable compared to the other two.

The first and second system can be compared by the detailed graphs below. For the first system, Figure 9 shows the AC Primary load served and unmet electrical load, Figure 10 shows the PV power outputand Figure 11 shows the Battery state of charge and input power. For the secondsystem, Figure 12 shows the AC Primary load served and unmet electrical load, Figure 13 shows the PV power output, Figure 14 shows the WT power output andFigure 15 shows the Battery state of chargeand input power.

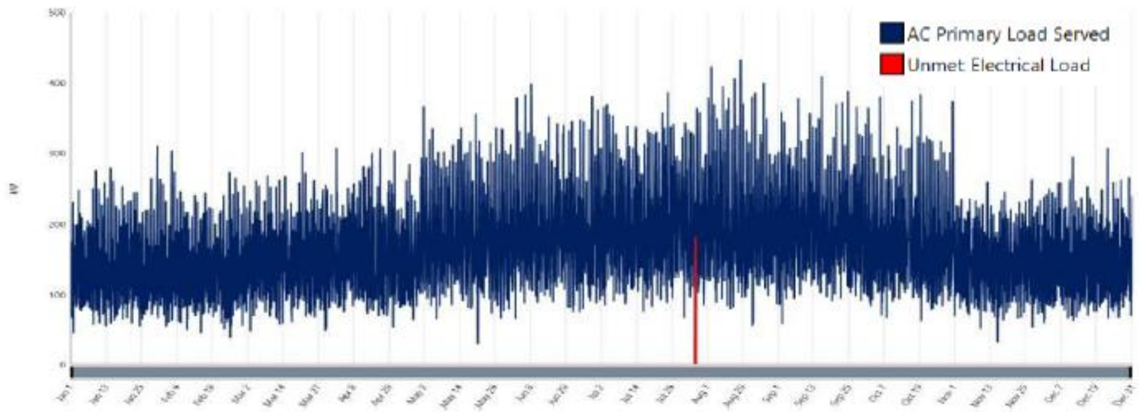

Fig 9 – Primary load served and unmet electrical load of PV/BAT system

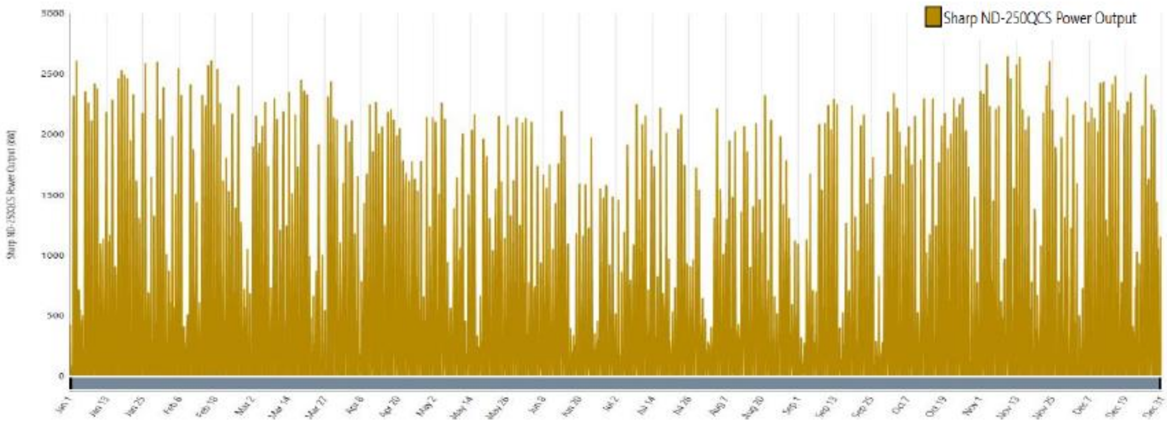

Fig 10 – PV power output of PV/BAT system

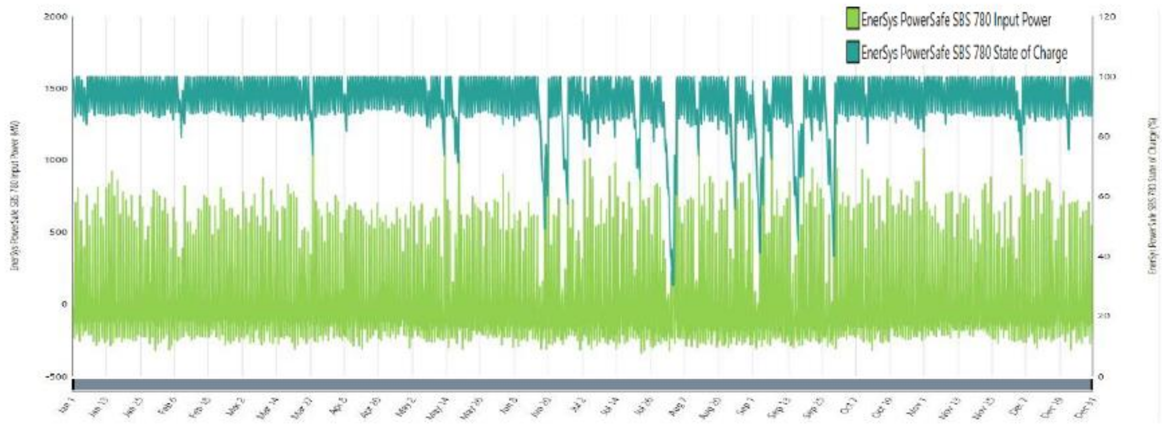

Fig 11 – Battery state of charge and input power of PV/BAT system

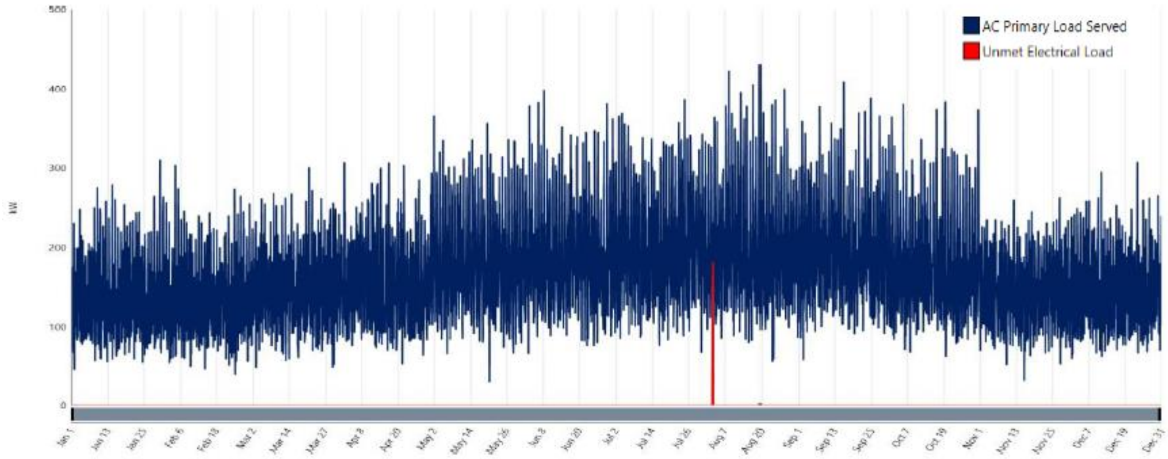

Fig 12 – Primary load served and unmet electrical load of PV/WT/BAT system

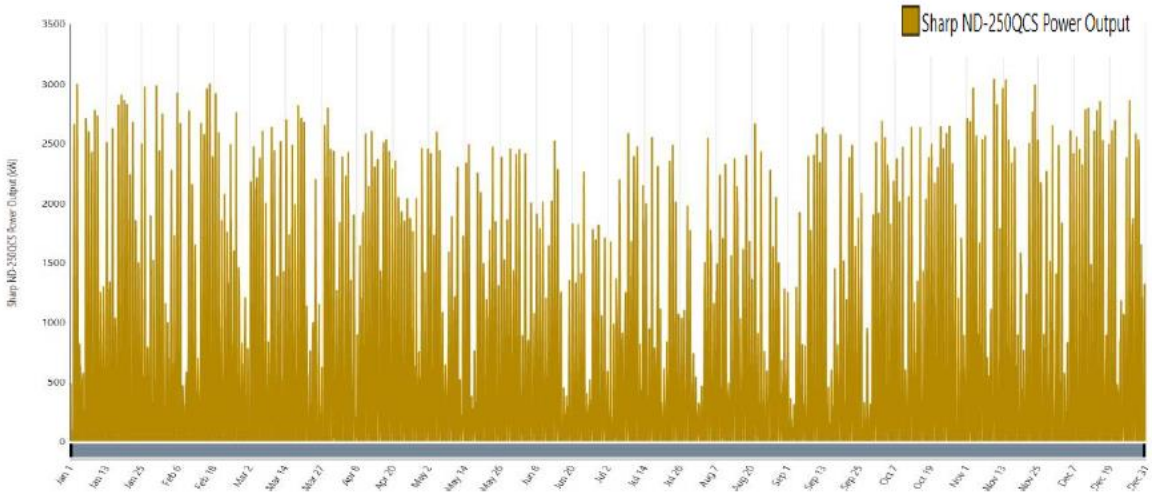

Fig 13 – PV power output of PV/WT/BAT system

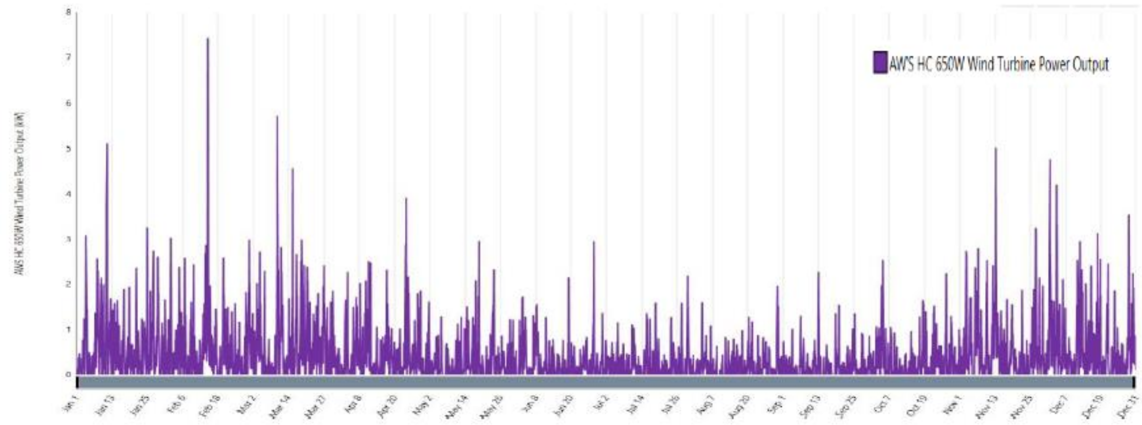

Fig 14 – WT power output of PV/WT/BAT system

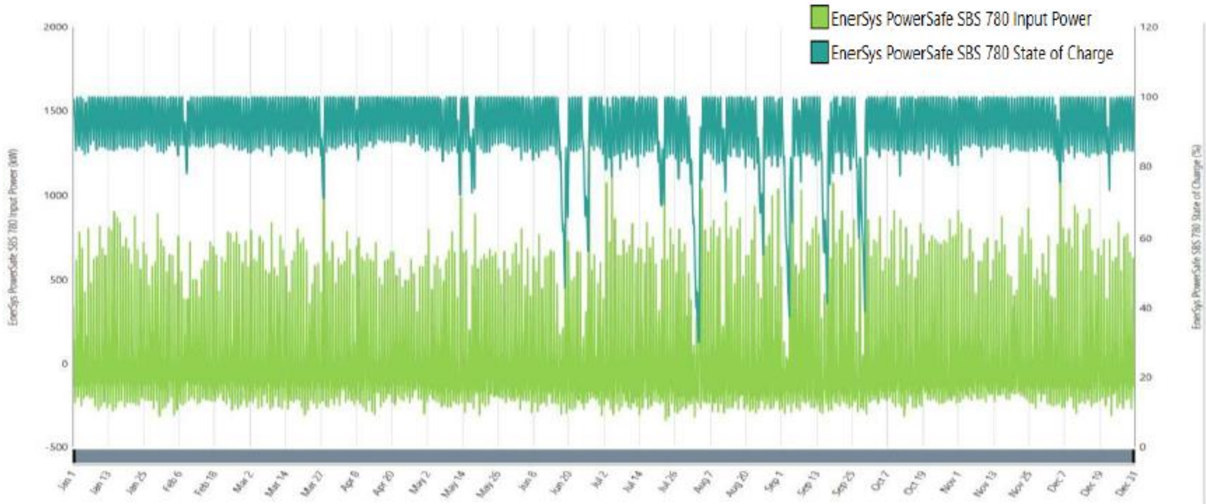

Fig 15 – Battery state of charge and input power of PV/WT/BAT system

From the graphs and tables above, it is quite evident that the PV generation, Load consumption and battery state of charge is almost similar for the both systems. Moreover, the WT generation is much lesser compared to the PV generation. As the second system also increases the initial cost without any significant benefits, thus the PV/BAT system should be preferred if the modelling is required to be done in an off-grid configuration.

From Table – 3, it can be seen that the excess electricity generation is quitehigh. This is due to the fact that the total electricity consumption is always less than the total electricity generation. The primaryreason for this that the peak load demand isquite high compared to the average load demand. Also, there is an unmet load whichshows how reliable the system is. To counter this the system is connected to a grid connection. Due to this, the excess electricity generated can be sold to the grid. This will earn revenue for the villagers and their economic conditions can be improved.

Table – 4 gives the optimizationresults when the system is connected to thegrid. Table – 5 gives the electrical data of the combinations of the components.

Table 4 – Optimization results of on-grid system

System (Ranked by least NPC)	PV (kW)	WT (Nos)	BAT (Nos)	PHES (Nos)	Conv (kW)	NPC ($)	COE ($)	Operating Cost ($/year)	Initial Capital($)
#1 PV/PHES/GRID	3964	-	-	2	1947	-220,472	-0.00327	-238,667	2.86 M
#2 PV/BAT/GRID	3964	-	38	-	1947	-192,692	-0.00284	-234,731	2.84 M
#3 PV/WT/PHES/GRID	3964	16	-	2	1947	-181,508	-0.00269	-238,499	2.90 M
#4 PV/WT/BAT/GRID	3964	8	38	-	1945	-171,485	-0.00253	-234,237	2.86 M
#5 PV/WT/GRID	3928	1668	-	-	18323.93 M		0.0555	-208,229	6.62 M

#6 WT/BAT/GRID	-	4878	834	-	117814.0 M	0.527	167,622	11.8 M
#7 WT/PHES/GRID	-	5053	-	32	124814.8 M	0.560	179,538	12.5 M
#8 WT/GRID	-	8955	-	-	236123.4 M	0.475	188,203	20.9 M

Table 5 – Electrical Data of on-grid system

System (Ranked by least NPC)	Electricity Production (kWh/year)	Electricity Consumption (kWh/year)	Excess Electricity (kWh/year)	Excess Electricity(%)	Unmet Load (kWh/ year)	Unmet Load (%)
#1 PV/PHES/GRID	6,016,006	5,209,564	652,723	10.8	1222	0.0235
#2 PV/BAT/GRID	6,061,002	5,245,596	693,483	11.4	1280	0.0244
#3 PV/WT/PHES/GRID	6,019,480	5,211,796	653,826	10.9	1214	0.0233
#4 PV/WT/BAT/GRID	6,055,739	5,241,490	692,402	11.4	1274	0.0243
#5 PV/WT/GRID	6,549,440	5,474,122	947,880	14.5	1144	0.0209
#6 WT/BAT/GRID	2,170,966	2,058,162	56,138	2.59	481	0.0234
#7 WT/PHES/GRID	2,236,115	2,049,020	53,079	2.37	493	0.0240
#8 WT/GRID	3,986,731	3,805,477	98,239	2.46	955	0.0251

From Table – 5, it can be observed that there is an unmet load in the system. This is due to the random grid outage which was set up during the modelling. This amount can effectively be brought to zero is the grid outage is completely eliminated. Itshould be taken into notice that this may change the NPC and thus the ranking of thesystems as more electricity can be sold to the grid. The values may change too depending on the time the outage occurs.

From Table – 4, it can be seen that the cost of the first system i.e., PV/PHES/GRID comes out to be the cheapest at a COE of $-220,472 and Initial capital cost of $2.86M. The cost of the second system of PV/BAT/GRID is higher at a COE of $-0.00284 but comes at a cheaper initial cost of $2.84M. The cost of the other six systems is however quite appreciable compared to the other two.

The first and second system can be compared by the detailed graphs below. Forthe first system, Figure 16 shows the AC Primary load served and unmet electrical load, Figure 17 shows the PV power output and Figure 18 shows the Battery state of charge and input power. For the secondsystem, Figure 19 shows the AC Primary load served and unmet electrical load, Figure 20 shows the PV power output, Figure 21 shows the Battery state of chargeand input power.

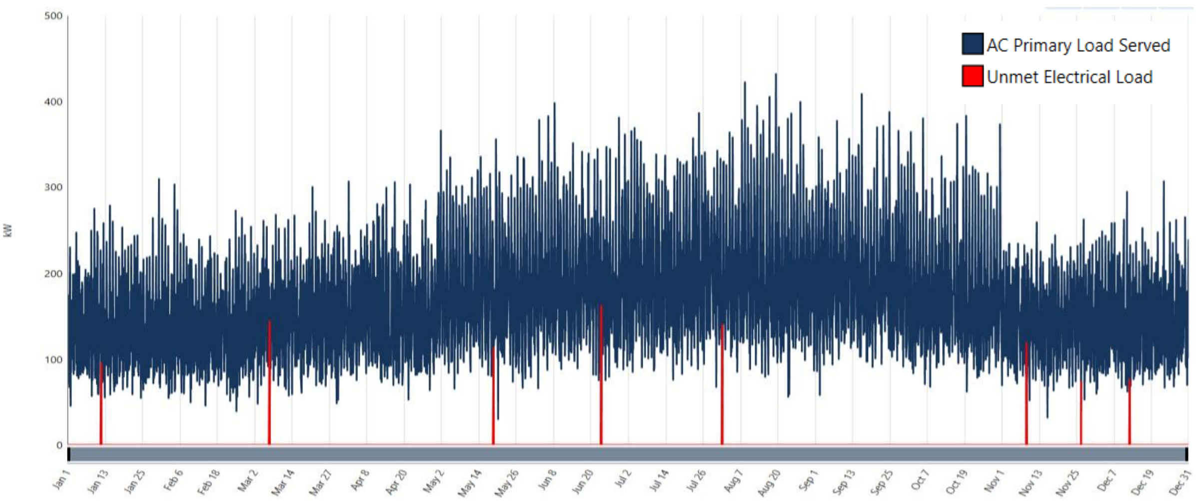

Fig 16 – Primary load served and unmet electrical load of PV/PHES/GRID system

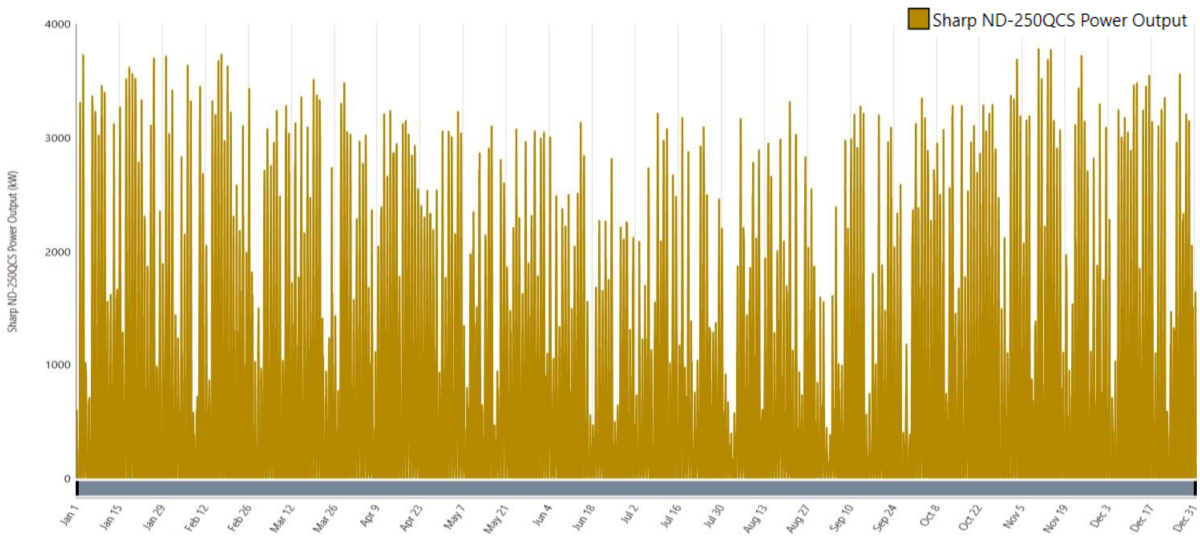

Fig 17 – PV power output of PV/PHES/GRID system

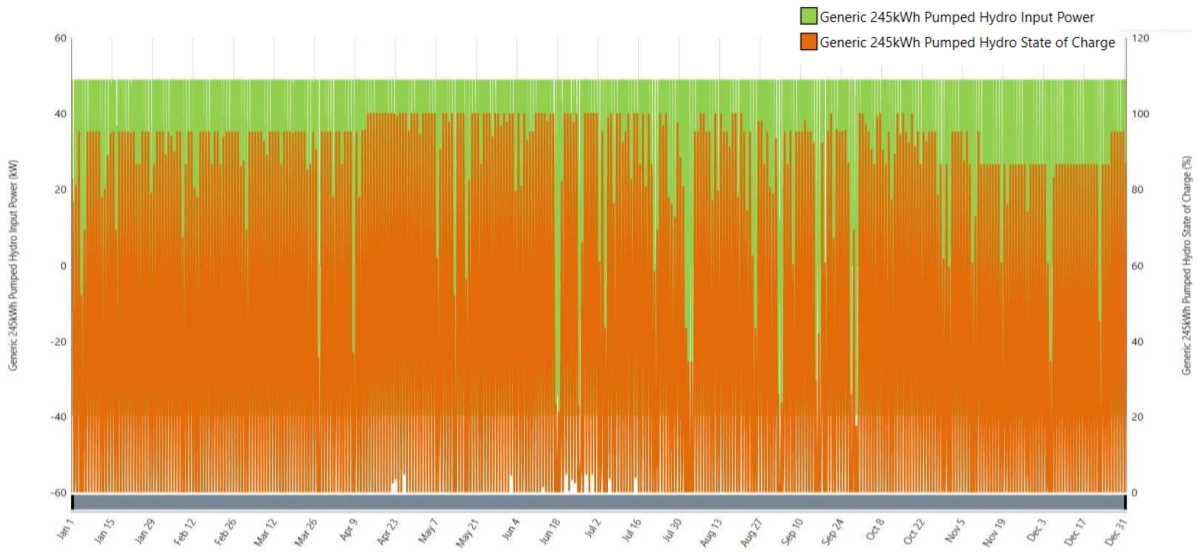

Fig 18 – Battery state of charge and input power of PV/PHES/GRID system

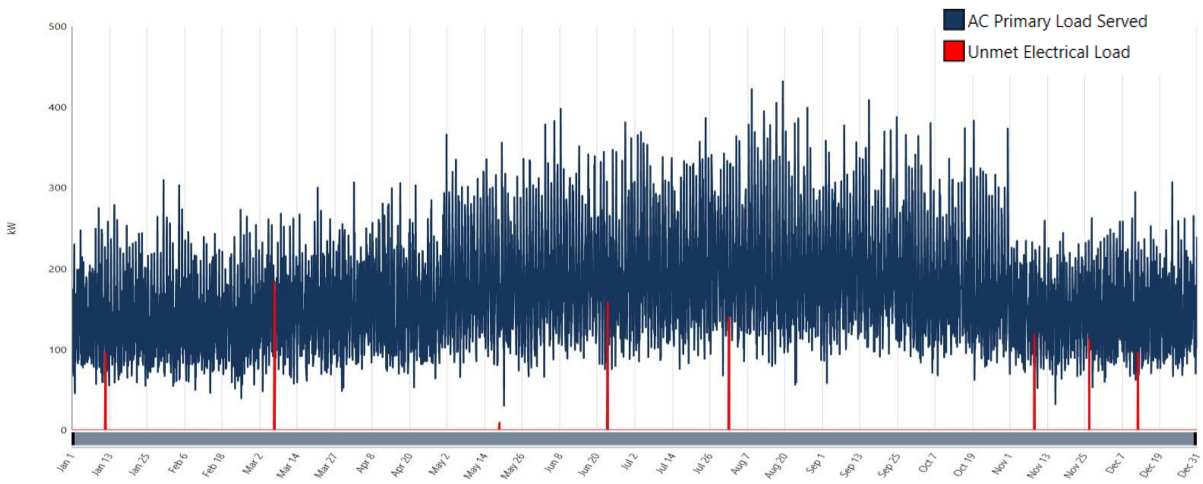

Fig 19 – Primary load served and unmet electrical load of PV/BAT/GRID system

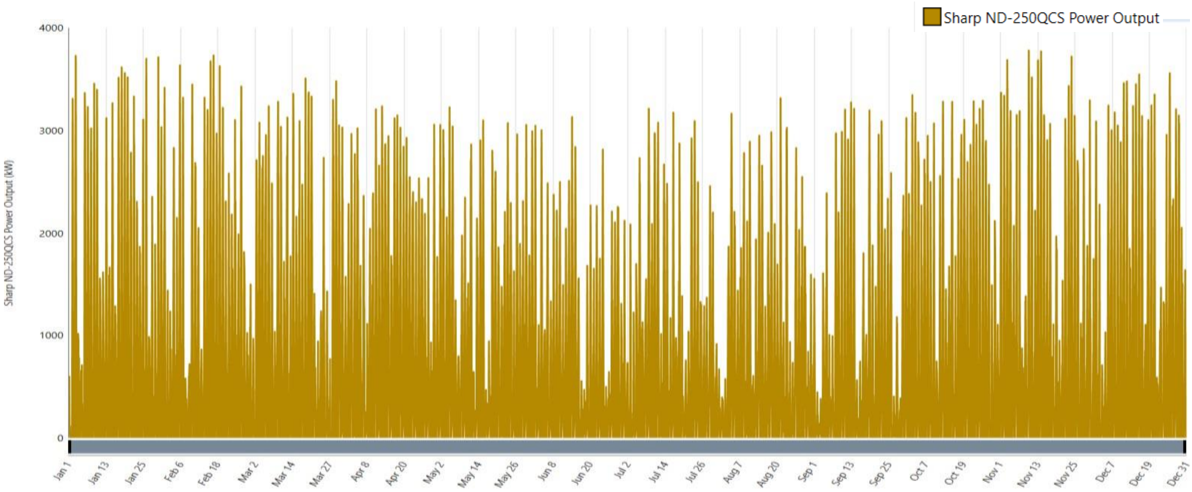

Fig 20 – PV power output of PV/BAT/GRID system

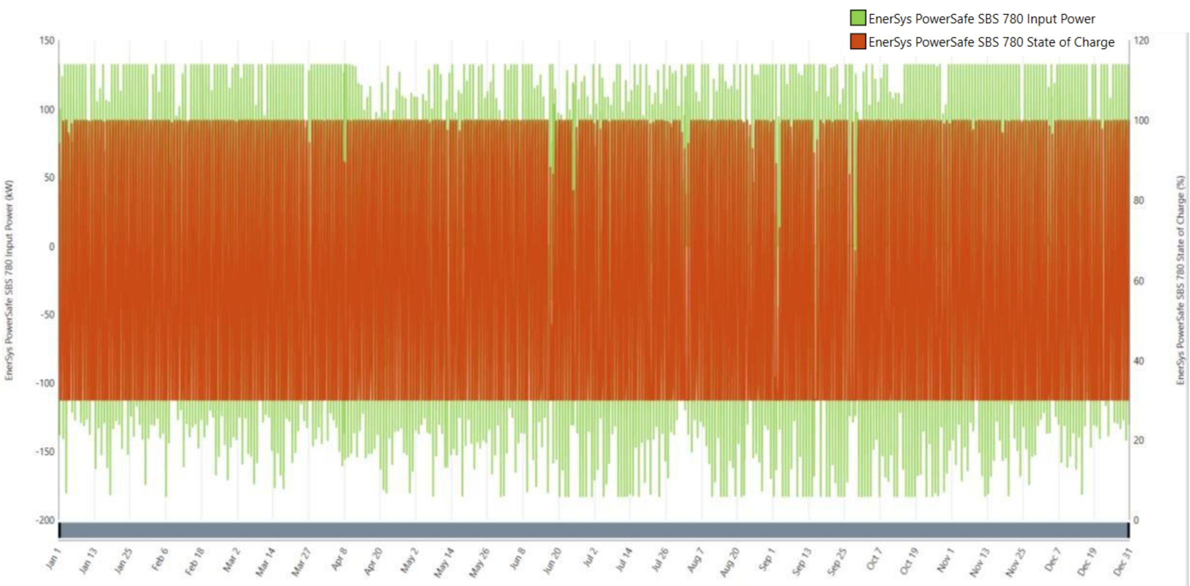

Fig 21 – Battery state of charge and input power of PV/BAT/GRID system

From the graphs and tables above, it is quite evident that the PV generation and Load consumption is almost similar for the both systems. However, the state of charge for the BAT and PHES differs greatly. The BAT has a more cycle frequency than the PHES. Due to this, the BAT might have a reduced life. Due to this the PV/PHES/GRID system should be preferred if the modelling is required to be done in an off-grid configuration.

The process of optimization can besummarized by the flowchart below -

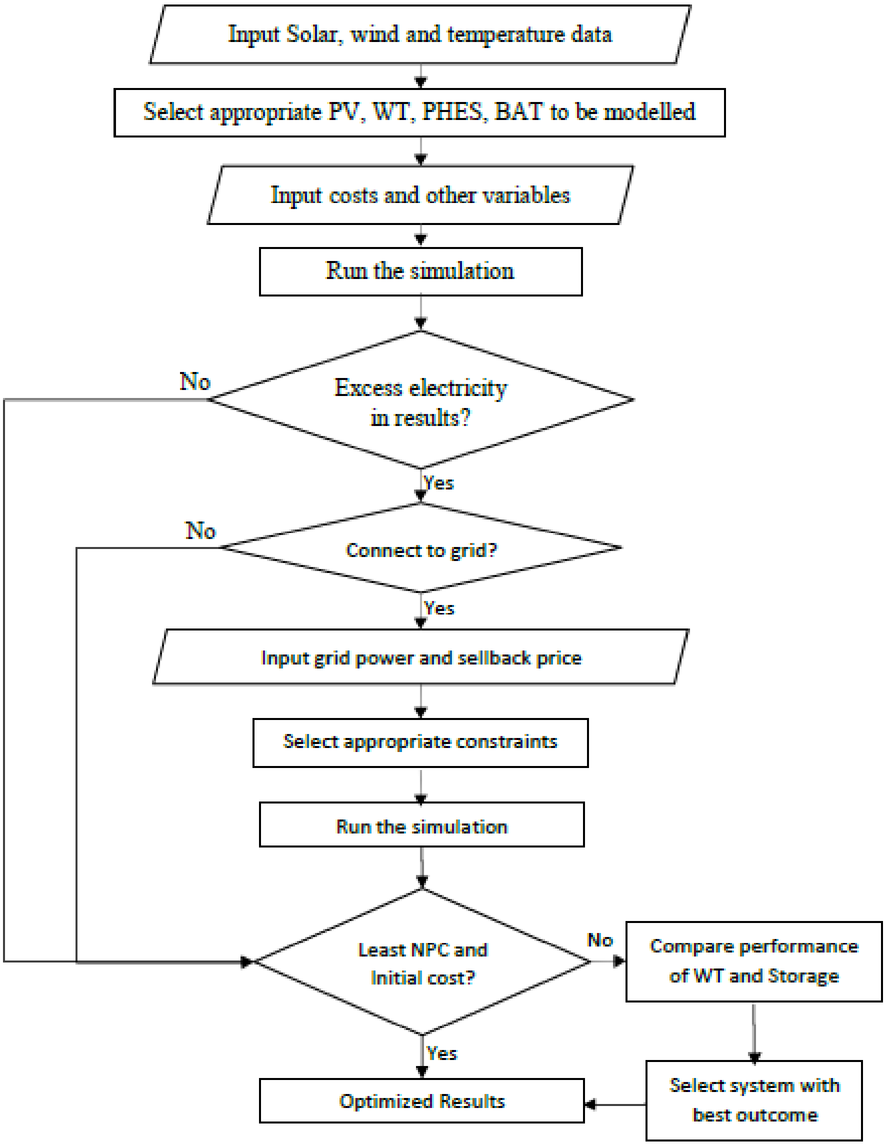

Fig 22 – Optimization Flowchart

VII. Conclusion

Thus, from this study it can be concluded that for the location of Bogamati,if an off-grid configuration is to be considered, the PV/BAT system would be ideal. For this system, a $2.68M initial capital investment is required. The village can be self-sufficient in terms of electricity production with a COE of $0.163 and NPC of $3.04M. Since there is a 60.5% excess electricity production in this configuration, the area can be connected to the grid systemand the excess electricity can be sold to thegrid. For the on-grid configuration, PV/PHES system should be ideal. For this system, a $2.86M initial capital investmentis required. Due to the presence of hills and the Lokhaitora river, the construction ofPHES would be cheap and simple. Due to more electricity sold to the grid as compared to the electricity bought during the peak hours to cater the unmet load, the COE and NPC will be $-0.00327 and $- 220,472 respectively. The gross amount earned by selling the excess electricity can be distributed among the villagers. This can greatly improve their economic condition. Moreover, this excess electricity generated can be used by the factories of Rangia and Guwahati through the grid and thus boost industries of the state. It can also be used bythe nearby districts as per requirements.

If such locations are identified all over the country and proper investment is done in renewable energy generation, a 24-hour electricity connection to each and every corner of the country can be a possibility. This can not only improve the condition of living of the people, but also increase industrial growth. The economy can prosper and the country can reach new heights. If electricity is produced in abundancy, the cost will also come down and thus making it affordable even for the poorest of the poor in the country. This study gives an example on how such HRES can be implemented and can be taken as a base case to apply such systems elsewhere.

References

[1]. Lawan, Salisu Muhammad. and Abidin, Wan Azlan Wan Zainal. (2020, February 26). A Review of Hybrid Renewable Energy Systems Based on Wind and Solar Energy: Modeling, Design and Optimization. https://www.intechopen.com/books/ wind-solar-hybrid-renewable- energy-system/a-review-of-hybrid- renewable-energy-systems-based-on- wind-and-solar-energy-modeling-design-and-optim.

[2]. Jahanbani, Fatemeh. and Riahy, Gholam H. (2011, November 9). Optimum Design of a Hybrid Renewable Energy System. https://www.intechopen.com/books/r enewable-energy-trends-and- applications/optimum-design-of-a- hybrid-renewable-energy-system.

[3]. Behera, Sasmita. and Pati, Bibhuti Bhusan. (2019, October 9). Grid- Connected Distributed Wind- Photovoltaic Energy Management: A Review. https://www.intechopen.com/books/ wind-solar-hybrid-renewable- energy-system/grid-connected- distributed-wind-photovoltaic- energy-management-a-review.

[4]. Arraez-Cancelliere, Oswaldo A. Muñoz-Galeano, Nicolás, and López- Lezama, Jesús M. (2019, September 13). Methodology for Sizing Hybrid Battery-Backed Power Generation Systems in Off-Grid Areas. https://www.intechopen.com/books/ wind-solar-hybrid-renewable- energy-system/methodology-for- sizing-hybrid-battery-backed-powergeneration- systems-in-off-grid-areas.

[5]. Khattab, Nagwa M. Badr, Mervat A. Shenawy, Essam Tawfik El. Sharawy, Hassan H. and Shalaby, Marwa S. (2020 March 25). Economic Analysis of Stand-Alone Hybrid Wind/PV/Diesel Water Pumping System: A Case Study in Egypt. https://www.intechopen.com/books/ modeling-simulation-andoptimization- of-wind-farms-andhybrid- systems/economic-analysis-ofstand- alone-hybrid-wind-pv-dieselwater- pumping-system-a-case-studyin- egypt.

[6]. Singh, Sweta. Kanwar, Neeraj. Zindani, Divya. Jadoun, Vinay Kumar. (2021, May 14). Decision making approach for assessing the suitable hybrid renewable energy based microgrid system for rural electrification in India. https://www.sciencedirect.com/scien ce/article/pii/S2214785321030935.

[7]. Arefin, Sk. Shezan. and Das, Narottam. (2017, June 28). Optimized Hybrid Wind-Diesel Energy System with Feasibility Analysis. https://link.springer.com/article/10.1 007/s40866-017-0025-6.

[8]. Okedu, Kenneth E. and Uhunmwangho, Roland. (2014, May 03). Optimization of Renewable Energy Efficiency using HOMER https://www.researchgate.net/publica tion/263765594_Optimization_of_R enewable_Energy_Efficiency_using _HOMER.

[9]. Bhandari, Binayak. Lee, Kyung-Tae. Lee, Gil-Yong. Cho, Young-Man. and Ahn, Sung-Hoon. (2014, December 07). Optimization of Hybrid Renewable Energy Power Systems: A Review. https://link.springer.com/content/pdf/ 10.1007/s40684-015-0013-z.pdf.

[10]. NITI Aayog. State Renewable Energy Capacity Addition Roadmap. Retrieved June 27, 2021 from https://niti.gov.in/sites/default/files/e nergy/Executive-Summary.pdf.

[11]. Ministry of New and Renewable Energy. Annual Report 2020-21. Retrieved June 27, 2021 from https://mnre.gov.in/img/documents/u ploads/file_f-1618564141288.pdf.

[12]. Government of Assam. State Renewable Energy Action Plan for Assam. Retrieved June 27, 2021 from http://www.indiaenvironmentportal.o rg.in/files/file/State%20Renewable% 20Energy%20Action%20Plan%20fo r%20Assam.pdf.

[13]. Koundal, Aarushi. (2021, March 10). Renewable energy potential of Assam stands at 14,487 MW, solar takes largest share. ETEnergyWorld. https://energy.economictimes.indiati mes.com/news/renewable/renewable -energy-potential-of-assam-standsat-14487-mw-solar-takes-largest share/81430856#:~:text=renewable %20energy%3A%20Renewable%20 energy%20potential,share%2C%20E nergy%20News%2C%20ET%20Ene rgyWorld.

[14]. NPTEL. Hybrid System. Retrieved June 28, 2021 from https://nptel.ac.in/content/storage2/c ourses/108108078/pdf/chap10/teach _slides10.pdf. 15. HOMER. HOMER Pro 3.14 User Manual. Retrieved June 29, 2021 from https://www.homerenergy.com/prod ucts/pro/docs/latest/index.html.