Global Journal of Researches in Engineering: F
Electrical and Electronics Engineering
Volume 18 Issue 1 Version 1.0 Year 2018
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Green Improving by Autonomous PV Mini-Grid Model in Central Myanmar

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GJRE-F Classification: FOR Code: 090699

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Strictly as per the compliance and regulations of:

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I. Introduction

Nowadays, the world is suffering impacts, Global Warming and Climate Change, results of previous Green House Gas (GHG) emissions from the usages of the fossil fuels. Renewables inherent possesses Sustainability due to the reliance upon infinitely available resources that are naturally recharging with Zero fuel cost, Clean, Green, Eco-friendly and no or fewer emissions. To create the better world for our next generations, Renewables promotion is the predominant backbone of all strategies towards Sustainable Future of Mother Earth [1].

UN's 2030 Agenda formulates a set of 17 Sustainable Development Goals (SDGs). SDG 7 urges to ensure access to affordable, reliable, sustainable, and modern energy for all. It is not only the Goal that explicitly addresses the energy sector and mentions Renewable Energy (RE) as a mean to achieve it but also crucial to gain the other SDGs. Renewables offer equally solutions to the problems of Local and Global Environmental Sustainability [9].

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a) *Background: Off-Grid Electricity Access*

About 95 % of 1.2 billion people without Grid Access live in sub-Saharan Africa, South and East Asia, with the remainder spread almost equally across the Middle East, Central Asia, and Latin America. Nearly 60% of additional generation needed to achieve universal electricity access by 2030 will come from Off-Grid options. Standalone Mini-Grids powered by Renewables provide electricity to 90 million people [4] and meet a hierarchy of needs, from lighting to productive uses, thereby enabling people to climb the energy ladder. These are cost-effective and can be installed in the modular fashion, linked to Grid-extension plans [9].

Myanmar is situated in the northwestern-most country on the mainland of South East Asia as the strategic location. The geographical coordinate is between latitude 9° 58´N and 28° 29´N; and longitude 92° 10´E and 101°10´E, the total area of 676,563 km^2, near to the Equator and along the belt of the sun's radiation, and availability of sun shine hour is average 6 to 7 hours in dry season. Myanmar has tremendous natural resources and potentials of Renewables. The country's Energy Policy encourages the development of RE. In 2014, Myanmar National Electrification Planning (NEP) targeted to electrify 7.2 million households and achieve universal access to electricity by 2030. In the long term, it expected that more than 95% of the population connected by the extension of National Grid System as a least-cost solution. In the medium term, Mini-Grids and Solar Home Systems (SHS) will play the role in providing electricity to the hundreds of thousands of households in the areas that National Grid will take many years to reach [8].

The key player of the implementation of the Off-Grid sector of the NEP is the Department of Rural Development (DRD) under the Ministry of Agriculture, Livestock, and Irrigation (MOALI). DRD is boosting Off-Grid Rural Electrification, and as a result, out of 63899 villages in total, 22911, nearly 36 % are electrified by the end of FY 2016-2017. That amount is 10 % increased than FY 2015-2016 [5-7]. From [7], villages powered by each type observed that 7507 by SHS (Solar Home System), 94 by PV Mini-Grid, 2769 by Diesel, and 1296 by Mini/Micro Hydro and 154 by Biomass/Biogas.

b) State-of-the-Art

Fig. 1 illustrates the State-of-the-Art. It is the combination of complicated works consists of different pieces and several steps. The site visit is the vital work to observe the real situation and the problems. Based on the site visit experience, the appropriate solutions and load profiles predicted. Besides, the resources studied. Energy, the technology, design, and the main components are selected. The parameters and costs validated. As the final and crucial work, the feasible models simulated in HOMER (Hybrid Optimization of Multiple Energy Resources) Pro (version 3.11.4) environment and then, the Optimum/Sustainable Model selected.

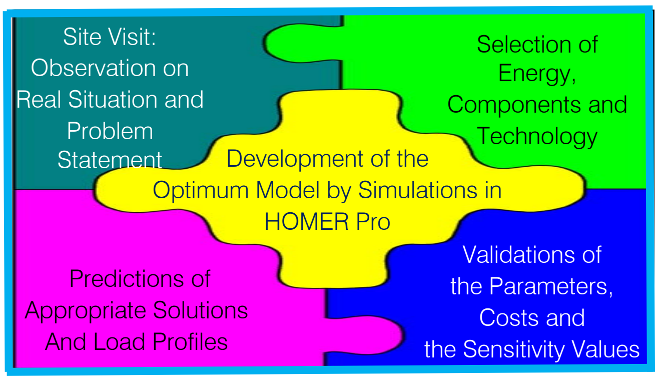


Fig. 1: State-of-the-Art

II. Site Visit: Ground Highlights

a) Location

(a) Village Map (b) State Map

Fig. 2: Satellite-Map of Nat Kan Lel (Nagale) [13]

A village Nat Kan Lel (Nagale) situated at geographical coordinate: Lat 20.922N and Lon 95.299E, near the National Park of famous Mount Popa in Kyaukpadaung Township, Mandalay Region, and Central Myanmar as shown in Fig. 2. It located at 10 km from National Grid System, 2 km from the road [11], and nearly 13 km from pozzolan mill.

b) Interviews and Data Collection

The village Nat Kan Lei is in the list of electrified villages. It observed that some existing electrification scenarios in rural areas are ineffective and inefficient systems [2]. Hence, the case study and data collection were performed at it in October 2017. There are 800 households with about 4000 population. Different places, Pagodas, Monasteries, water tube-wells, Diesel Mini-Grids, Rural Health Clinic (RHC) and high school observed. About 100 villagers from different roles were interviewed as obviously reflected in Figs. 3 to 6.

Fig. 3: Interview with the Village Authorities

Fig. 4: Interview with the Owners of Water Tube-Well

Fig. 5: Interview at RHC

Fig. 6: *Interview with the Owner of DG3*

c) Diesel Mini-Grids

That village is currently powered by three self-reliant Diesel Mini-Grids: DG1 (10 kW), DG2 (15 kW), and DG3 (15 kW) to 3 clusters; each has about 100 households. 3 Pagodas, 3 Monasteries and street lightings are also supplied by DG3. The single-phase, Synchronous type, 4-pole, 1500 rpm, 50 Hz low-cost Generators are operated with belt-drives from the Diesel engines. The capacities are engine 22 HP (horsepower) with 10 kW Generator and engine 25 HP with 15 kW Generators. Their service years are: DG1 is ten years; DG2 and DG3 are five years. It found that another Diesel system (22 HP Diesel engine with 10 kW Generator) for water pumping at the DG2 site as identified in Fig. 7.

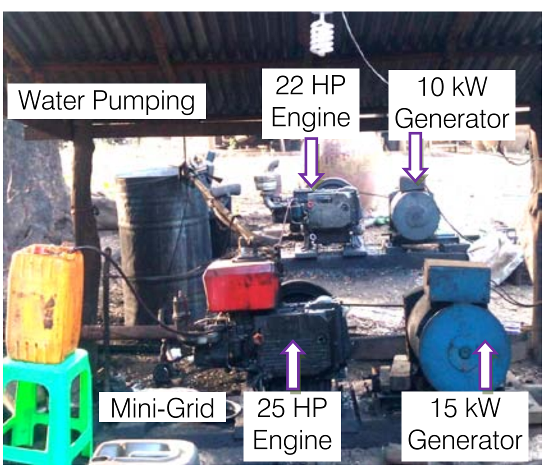


Fig. 7: *View of the Machines at DG1 Site*

These are usually operating for only 3 hours per day, from 18 hr to 21 hr in the cold season (November, December, January, and February) and from 19 hr to 22 hr in the other months.

As the other Off-Grid villages, monthly tariff is 2000 MMK (nearly 1.5 $) for 2ft FL (20 W Fluorescent Lamp) or 26 W CFL (Compact Fluorescent Lamp) and 5000-6000 MMK (3.8-4.5 $) for the combined use of 2ftFL, mobile phone charging and TV (Television). Sometimes, the extra operating hour requested from the villagers and then, the charge is 2000 MMK per hour for each generator. Additionally, there are other Diesel Generators (each 10 kW) at Pagodas, and Monasteries. Only the fuel cost is needed to pay; then, these operated for the donation events.

d) SHS

At Village Nat Kan Lel, SHS with conventionally ground-mounted and rooftop structures found. Fig. 8 (a) mentions the rooftop PV modules (each 300 W) at one home and Fig. 8 (b) shows the ground-mounted PV (960 W) modules at the clinic. Fig. 9 highlights the villagers and their mounted PV (300 W) module.

(a) Rooftop PV (b) Ground-Mounted PV

Fig. 8: PV System Deployments at Village Nat Kan Lel

Fig. 9: The Villagers and their PV Module (300W)

250 households have SHS and deployed PV modules are the polycrystalline type, and the ratings are from 100 W to 300 W and are made in China and Thailand. The maximum installed capacities of PV modules are up to 600 W at the households and 960 W (for vaccine refrigerator) at RHC. All the batteries are 12 V and average ratings are 60 Ah to 200 Ah. Two per households mostly used. These are made in Myanmar, China, and Thailand. The inverters are 300 VA, 500 VA, 100 VA and 1500 VA. These are made in Myanmar and India.

Fig. 10 significantly reflected that the villagers do not install or use the charge controller that maintains the battery within the operation limits and its lifetime. Also, it contributes the substantial cost factor, and there may be undesirable hazards as a consequence of the overcharging of the battery in the tropical areas. Thus, it is needed to aware the villagers to use it.

Fig. 10: The Villager and Components of his SHS

III. Problems and Demands

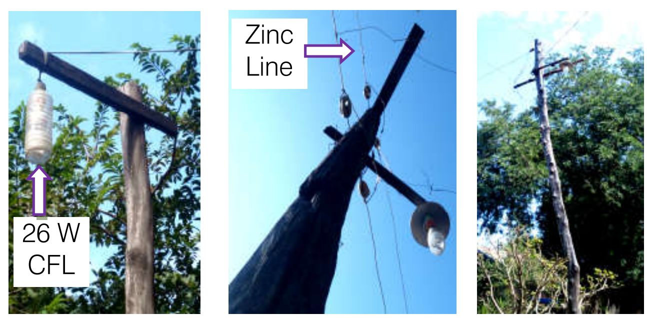
a) Generation Systems

Due to the interviews' results, 100 % of the local villagers desire Electrical power supply for the whole day. They believe that it will be developed if they access 24-hour supply. The operating time of DGs is a few hours per day, and also SHS cannot perform 24 hour supply. Besides, they do not obtain the sufficient power. Furthermore, there are design and quality issues. It observed that the DG systems required to repair and maintenance. Its replacement costs of spare parts for two months are about 25 $ to 35 $ for each machine.

Also, the overhauling per year is about 80 $ to 100 $ for each machine. Hence, the combined of all machines for long years may be quite large. Also, the total Diesel fuel cost is for 20 years. Then, the sum of the maintenance cost and fuel cost for all Electrical and Mechanical machines may be tremendously large. Another problem is the possibility of fire hazards from the Diesel storage tank. Moreover, there is significant noise and emissions from the DGs.

b) Distribution System and Loads

Currently, the villagers are commonly using the lightings as 2 ft FL, 26 W CFL (Compact Fluorescent Lamp), rechargeable DVD player, 21" TV and mobile phone charger. Fig. 11 mentions the current situation of the distribution lines from Diesel Mini-Grids. There are about 100 streetlights are using 26 W CFL. Total numbers of CFL in that village is nearly 600. CFL is Energy saving. But, it has hidden Environmental Impacts dealt with mercury content in the tube [14, 15]. Due to the study in [16], it is evident that there are multiple negative impacts of CFL as shown in Fig. 12.



(a) Streetlight (b) Distribution Pole (c) Bent Pole

Fig. 11: Distribution System of Existing Mini-Grid

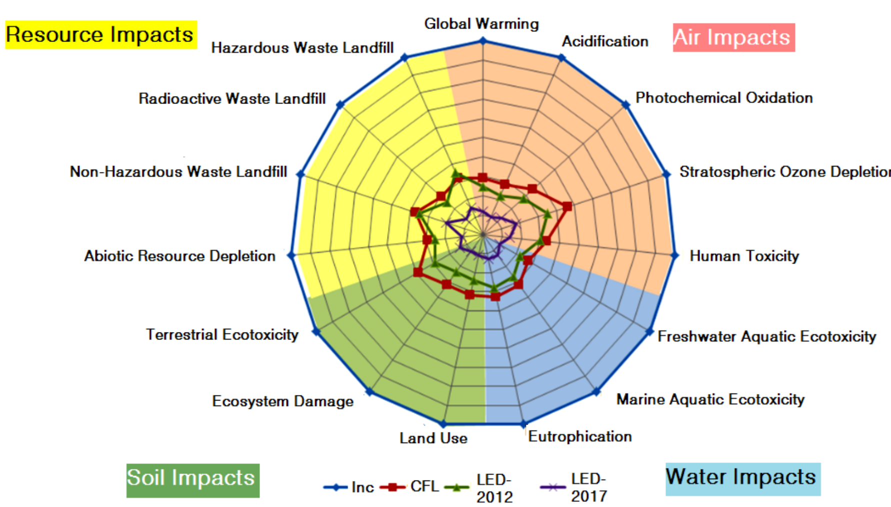


Fig. 12: Different Impacts from the Lighting Loads[16]

Due to the study in [16], it is evident that there are multiple negative impacts of CFL as shown in Fig. 12. Also, there are harmonics problems, high reactive power demands, and power factor problem by using FL and CFL. Due to evaluation in [17], the aggregated sum of the injected harmonics by FLs and CFLs in residential houses and commercial buildings contributes to the increased current distortion within distribution systems.

From Fig. 12, LEDs are more environmentally friendly, cost-effective and Energy efficient than CFL and incandescent lights [16]. From Fig. 11(b), the conductor is Zinc. The conductivity of Zinc is lower than others [18]. Thus, it should be changed to conducting lines, also other design issues.

There are other problems concerned with the Distribution board of one of Mini-Grid as shown in Fig. 13. Such kind of board can be dangerous for electrical hazards. Therefore, these should change. Also, the installations at some houses needed to renovate

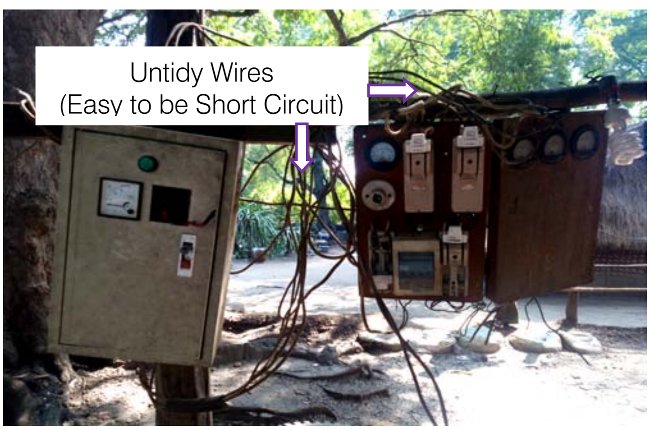


Fig. 13: Distribution Board of Mini-Grid

c) *Wood Energy for Cooking*

Fig. 14: Conventional Firewood Cooking at Village

The rice and curry are daily main food as well as traditional donation food in Myanmar, especially at the village. Consequently, the villagers always apply the firewood for cooking. Also, they use it for making Myanmar traditional snacks and the tea. Fig. 14 reveals how the villagers are cooking at the focused village. Consequently, the negative impacts are:

i. *Deforestation towards Climate Change*

Based on the collected data, average fuelwood consumption per household is 7 to 8 tons per year. Besides, there is other fuelwood consumption for the donation events. Then, the total fuelwood consumption for the whole village is nearly 6000 tons per year. That amount will cause the significant impacts of deforestation, and as a consequence, Climate Change will contribute.

ii. *GHG Emissions towards Global Warming*

CO_2 Emissions from the burning wood is 109.6 kg CO_2 per GJ [19]. Other chemicals are produced, including nitrogen dioxide; 200 g of CO_2 equivalent per kg of wood burnt, the gas is 300 times more potent as a greenhouse gas than CO_2 and lasts 120 years in the atmosphere. Methane produced (70 g of CO_2 equivalent per kg of wood) – 21 times more potent than CO_2. Carbon monoxide is also in large amounts. Overall, although figures vary depending on a multitude of factors, there is no doubt that wood burning is contributing to Global Warming [20]. Due to [27], the Emissions from fuelwood consumption at that village calculated as nearly 8981128 kg CO_2/year.

iii. *Health Problems from the Wood Burning*

The health implications of wood burning derive from the emissions which contain carbon monoxide, nitrogen dioxide, and particulates, as well as other noxious gases [20]. More than four million people die each year from illnesses attributable to indoor air pollution from cooking with traditional biomass and inefficient cook-stoves. For the one billion people who depend on health facilities in remote and rural areas that presently lack electricity [9, 21].

iv. *Cost for Fuelwood*

According to the interviews' results, the monthly fuelwood per household is 5 $. Then, the total cost for the whole village is 48000 $ per year. That amount calculated for the fuelwood usage in the households. It is sure that there is more cost of the fuelwood combination with the fuelwood cost for donation ceremonies.

v. *High Possibility of Fire Hazard*

Due to site study, there is easy to be fire hazard from the combinational effects of conventional firewood cooking and the constructional materials of the rural house. It located in the Central Dry Zone Area that is also easy to be the fire hazard due to its weather condition. Moreover, there is Diesel fuel storage for

Diesel Mini-Grids. The combinational effects of these three causes may lead to being the high possibility of fire hazard towards damages.

d) Vital Needs of the Water

The water predominantly need for the life of human being. It is essential for daily uses: drinking, cooking, cleaning, showering, washing the clothes and others, food, waste disposal, and the recreation. The soil of the village Nat Kan Lel is blessed for agricultural businesses: especially for the fruits such as dragon fruit, tamarind, mango, banana, and the seeds (sunflower and the nuts). The villagers achieve the income of 2200 to 2950 $ from planting of the mango for one acre. They also gained the income of 5162 $ from planting of the one acre dragon fruit. Thus, the water is also vitally needed for the crops production livestock at that village.

The interviews results identify that average water need for each villager is about 25 gallons per day. Then, the water needs (including the agriculture) for the whole village is around 120000 gallons (454249 liters) per day.

It observed that there are seven water tube-wells (including one well at RHC) in that village to fulfill the water needs. Among these tube-wells, the one tube-well is supported by the Government in June 2010. That tube-well was deepest (600 ft depth, 4 inches diameter, 2200 gallon per hour) and its water has pH (power of Hydrogen) 7.5. Humans have a higher tolerance for pH levels, and drinkable levels range from 4-11 [22]. Hence, the villagers obtained the drinking water from it. There is 5000 gal water storage tank at that tube-well. The others are 300 depths with 3 inches diameters. The tube-well of RHC has 5000 gal water storage tank, and the others have their tanks around 4000 gal storage. The village has other rain water storage facilities at the monasteries and households as reflected in Figs. 15 and 16.

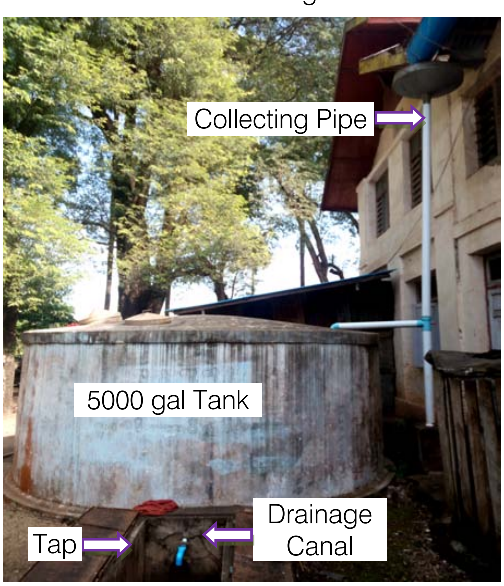


Fig.15: Rain Water Storage at the Monastery

Fig. 16: Rain Water Storage at the Household

e) Energy Needs for Small Enterprise

During the ground visit, it saw that there are two categories of the industrial loads dealt with the small enterprises. The former is needed for daily use as revealed in Figs. 17 and 18. The latter are required for seasonal use. Two oil mills usually operate during the harvest periods. The villagers want to develop small enterprise like carpentry workshop and others when they achieve sufficient Electrical Energy. Currently, the annual Diesel fuel consumption is about 500 gal (1893 liters) per year. Then, from [28], the emissions evaluated as 4995 kg CO_2 per year at that village.

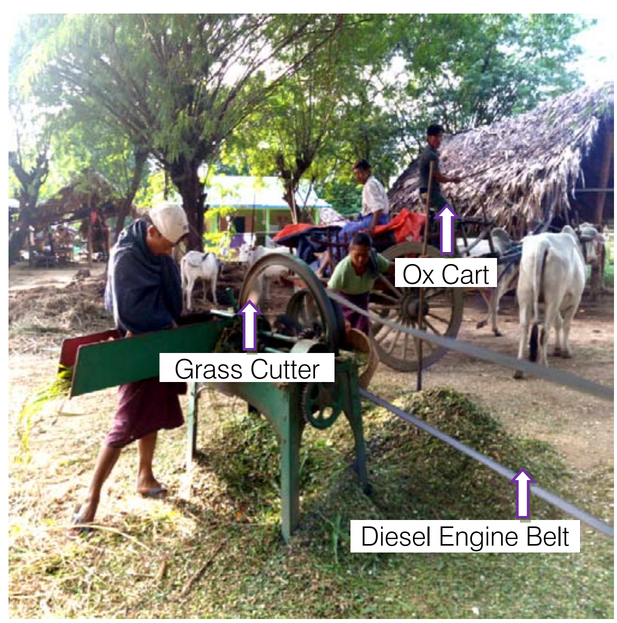


Fig. 17: Villager is Grass Cutting for Cow-Feed

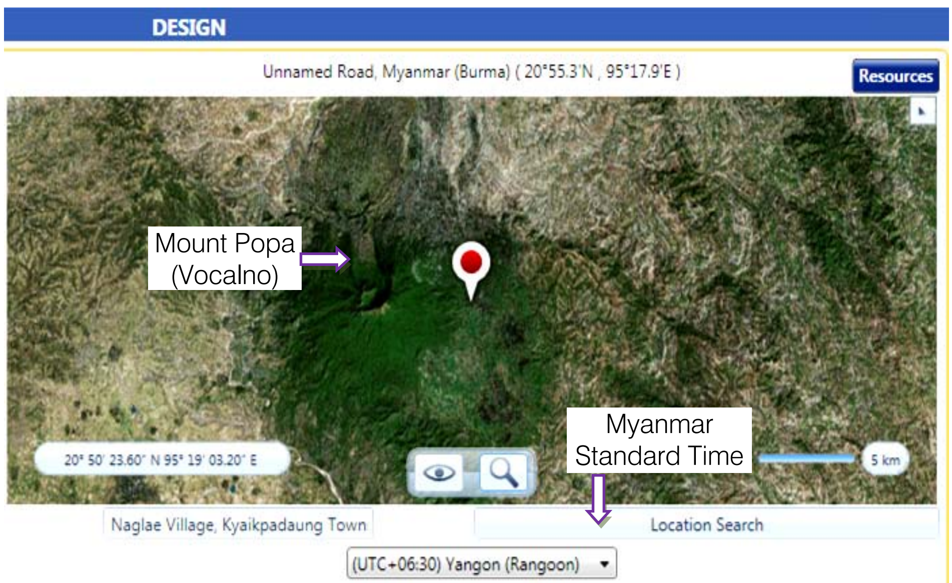
Fig. 18: Drilling Machine at Rural Workshop

IV. Autonomous PV Mini-Grid Model in HOMER Pro

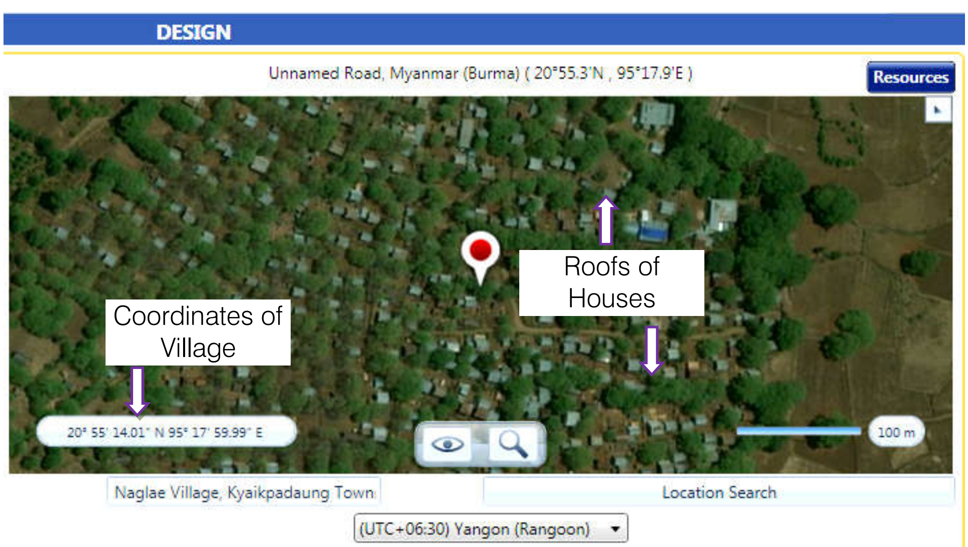
Based on the site visit data, Autonomous or Standalone PV Mini-Grid modeled in HOMER Pro. Firstly, it is important to locate the project. Then, the parameters are inputted step by step as the follows.

a) Location in the Map-Box of HOMER Pro

The village searched in the map-box of HOMER Pro with its geographical coordinate and Myanmar Standard Time: six hours and thirty minutes ahead of GMT (Greenwich Mean Time) as shown in Fig. 19.



(a) Aerial Region View of Village Nat Kan Lel (Naglae) near Mount Popa



(b) Aerial Zoom of Village Nat Kan Lel (Naglae)

Fig. 19: Location of a Village Nat Kan Lel in the Map-box of HOMER Pro

b) Economics, Constraints and Sensitivity Values

The Economics parameters inserted with the sensitivity values for the analysis. Discount rates and the inflation rates took from [12, 23]. The Currency set as US Dollar ($) in the Economics menu box in HOMER Pro. The parameters of the Constraints: Annual capacity shortage and Project lifetime are also validated. For Operating Reserve as a percentage of loads, Load in current time step set as 10%.

c) Input of the Resources

GHI (Global Horizon Irradiation) is the key parameter for designing of PV power generation system. The highest GHI identified in the central lowland area of Myanmar where average daily totals reach yearly total of 1900 kWh/m^2 (average daily total up to5.2 kWh/m^2) or higher [24]. In this work, GHI is downloaded from NREL (National Renewable Energy Lab) database in HOMER Pro. It is evident that the downloaded GHI data as mentioned in Fig. 21 are relevant with the map data of Fig. 20 [25]. It is also appropriate with [26]; Central Dry Zone Area of Myanmar (Magway, Mandalay, and Sagaing regions) is highly suitable with average radiation of more than 5 kWh per m^2 per day and limited variation in radiation during the rainy season. Hence, the proposed project located in Mandalay region is very feasible to implement PV Mini-grid system. The required temperature data also downloaded from NREL in HOMER Pro.

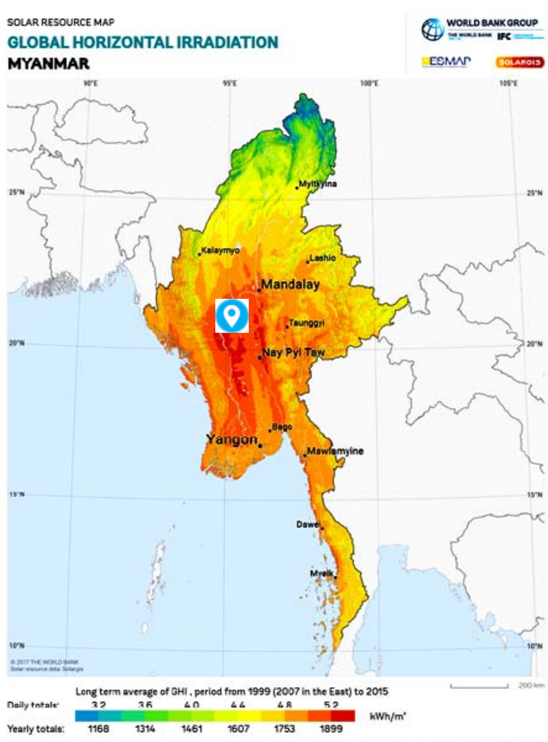


Fig. 20: GHI of Myanmar [25]

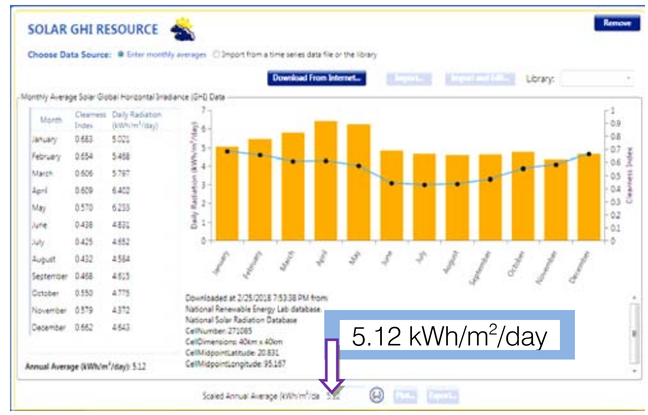


Fig. 21: GHI of Village Nat Kan Lel

Average wind speed required for modern wind turbines is at least 6 m/sec; most of Myanmar considered unattractive as average wind speeds are below 4 m/sec, except for coastline and mountain ranges such as Shan and Chin states [26]. The focused village not located in these states. Again, the wind speed is also downloaded in HOMER Pro, just to know its wind potential how many (with Anemometer height 50 m) at that location. Then, it found that Scaled Annual Average is 3.08 m/sec. That value is relevant to the above point. Hence, the wind system is not feasible.

During site study, there is no hydropower site around the focused village. For more confirmed, it investigated from [11]. The resulting figure obtained as highlighted in Fig. 22. Then, there is only one left, PV Mini-grid to create zero emissions power generation.

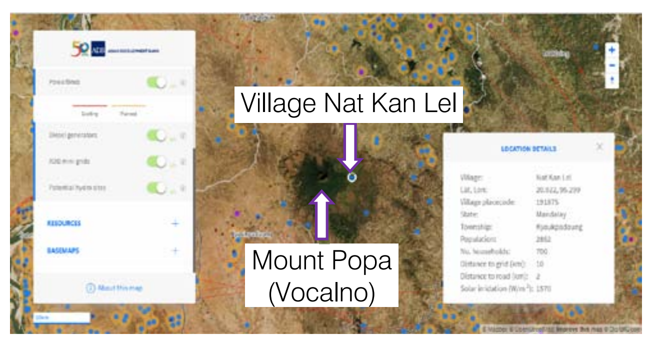


Fig. 22: Investigating the Potential of Hydropower [11]

d) Demand Scenarios

According to the data collection from a site visit, the demand scenarios inputted. These predicted for 3 Pagodas, 3 Monasteries, 800 households (HH), RHC and High School. Based on load consumptions, HH is distinguished as 500 low power consumption HH, 200 medium power consumption HH and 100 high power consumption HH. Combined with lighting and TV loads are inputted as primary electric load 1 with 293.6 kWh per day and 92.5 kW peak as described in Fig. 23.

These considered with LEDs due to the negative impacts of CFL that mentioned in sub-session III-A.

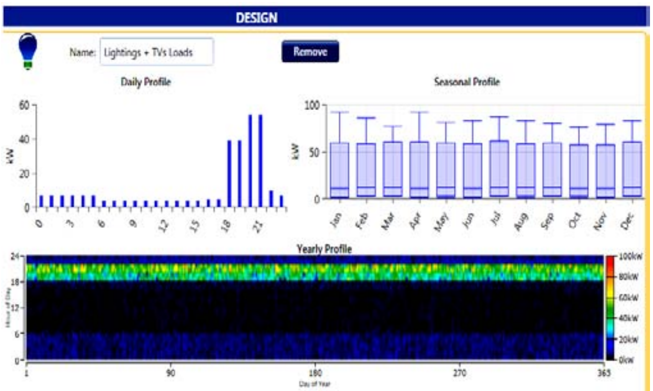


Fig. 23: Inputs of Lightings and TV Loads

As reported in sub-session III-C, the firewood cooking causes the significant drawbacks including Environmental impacts; Global Warming and Climate Change. To solve these issues, electric appliances (rice cooker, Cooking Pot, and Kettle) are involved in the demand scenarios. The industrial loads combined in primary load 2 of HOMER Pro. Then, kitchen and industrial loads inputted; 2085.72 kWh per day with 498.85 kW peak as reflected in Figs. 24 and 25.

Also, the other loads; small charging (mobile phone chargers, power banks, rechargeable LED torches and lanterns) and water pumping loads are inputted as the deferrable loads in HOMER Pro. From Fig. 25, its rating can be seen as 120.05 kWh per day and 48.5 kW peak.

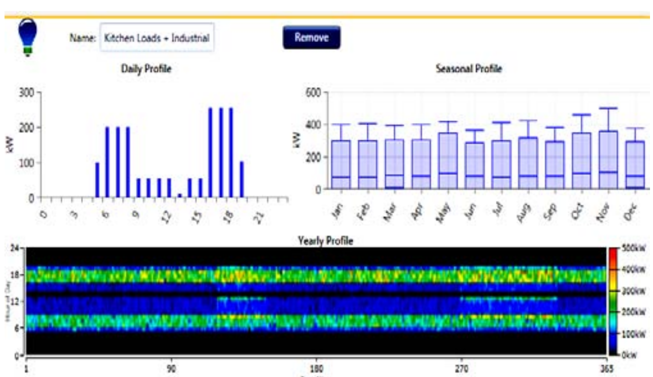


Fig. 24: Inputs of Kitchen and Industrial Loads

e) PV Mini-Grid Model in HOMER Pro

As mentioned in IV-C, only PV is reliable at the focused location. Thus, PV arrays are involved. At night time, PV cannot generate. Hence, the storage battery bank considered for the backup power system as proposed in Fig. 23. Then, the DC (Direct Current) power in the battery bank is transformed to AC (Alternating Current) Power by the converter to supply the AC Demands.

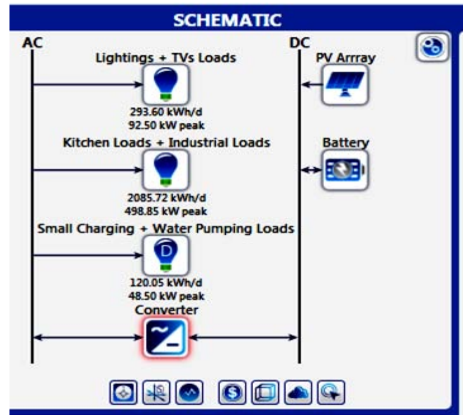


Fig. 25: Proposed PV Mini-Grid Model (100%RE)

f) Components of Autonomous PV Mini-Grid

The parameters of the main components of Autonomous PV Mini-grid modeled in HOMER Pro. The costs of PV for 1 kW are: Capital cost 950 $; Replacement cost 0 $; Operation and maintenance cost 10 S/year. The advanced input is the ground reflectance 20% and the array (panel) slope is 20.92°. Temperature inputs with Sensitivity values are set with PV Array temperature coefficient (%/°C) -0.43, -0.45 and -0.47 linked with PV Array operating cell temperatures 43; 45 and 47 as mentioned in Fig. 26. The battery inputs for 1 kWh are: Capital cost 200 $; Replacement cost 160 $; Operation and maintenance cost 20 S/year; lifetime ten years. The converter inputs are: for 1 kW are: Capital cost 340 $; Replacement cost 280 $; Operation and maintenance cost 5 S/year and lifetime fifteen years.

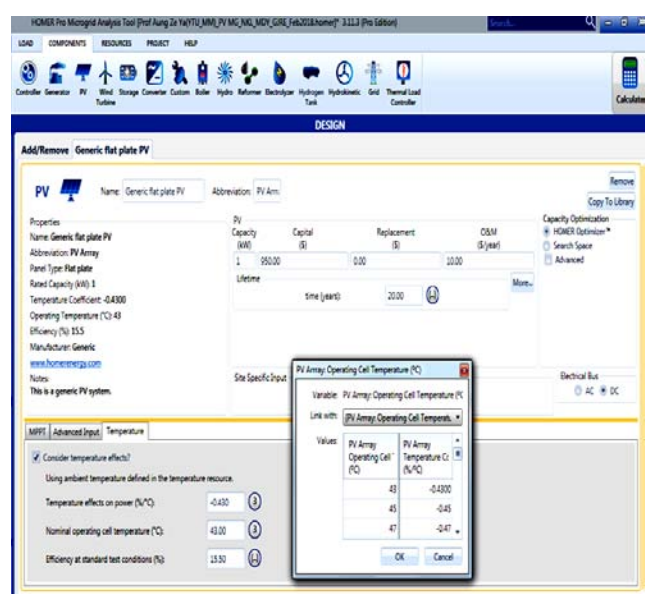


Fig. 26: Inputs of PV System in HOMER Pro

g) Diesel Mini-Grid Model in HOMER Pro

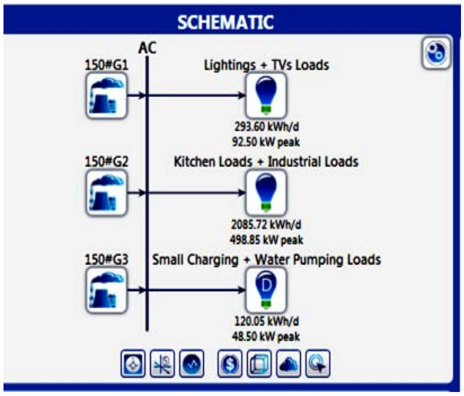


Fig. 27: Diesel Mini-Grid Model (100% NRE)

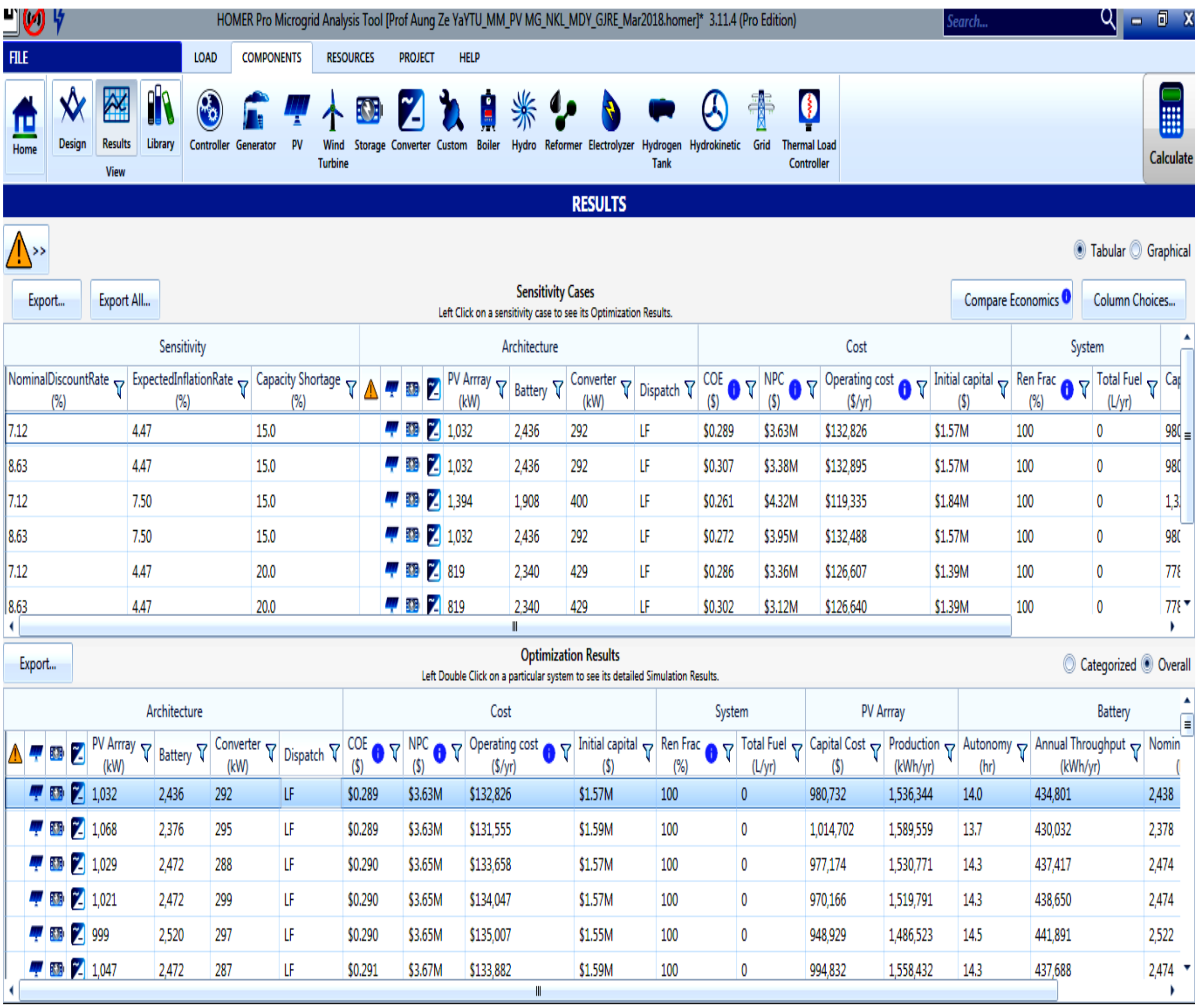
Fig. 27 shows the model of Diesel Mini-Grid with three 150 kVA Diesel Generators for same demands of the focused village to investigate the impacts of Diesel System. It is also for comparison of 100% RE System and 100% NRE (Non-Renewable Energy) System. The inputs are Diesel price 0.62 to 0.72 $/L (for Sensitivity Analysis), Capital cost 52500 $; Replacement cost 52500 $; Operation and maintenance cost 2 $ per hour for Diesel Generators.

V. Results And Discussions

a) Comparison of Two Models

In HOMER Pro, the thousands of PV and Diesel Mini-Grid models simulated with the mix-analysis of Techno-Economic feasibilities.

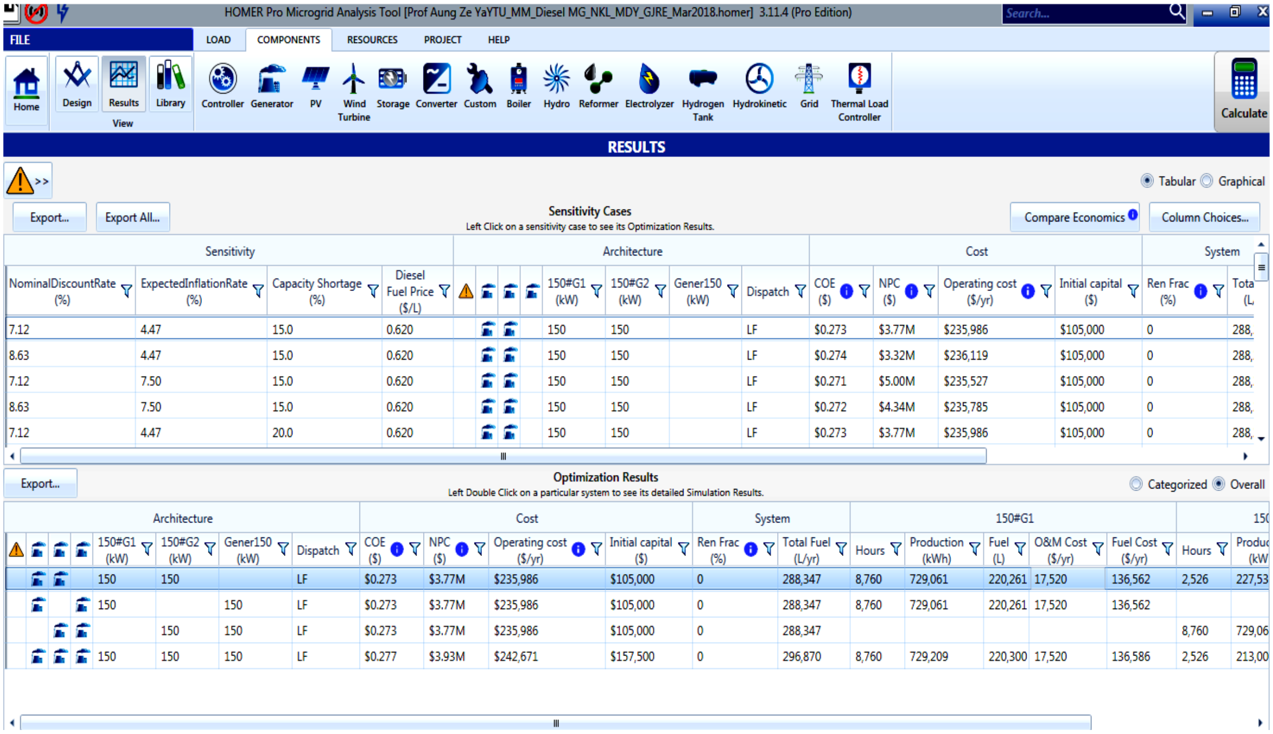
Then, the optimum designs are achieved with the Tabular results of different portions (architecture, cost, system, and each component) as mentioned in Figs. 28 and 29. The upper table is Sensitivity results, and the lower one is Optimization results. The optimum model is at the first row of these tables.



Sensitivity: NominalDiscountRate (%)	Sensitivity: ExpectedInflationRate (%)	Sensitivity: Capacity Shortage (%)	Architecture: PV Array (kW)	Battery	Converter (kW)	Dispatch	Cost: COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	System: Ren Frac (%)	Total Fuel (L/yr)	Ca
7.12	4.47	15.0	1,032	2,436	292	LF	$0.289	$3.63M	$132,826	$1.57M	100	0	98
8.63	4.47	15.0	1,032	2,436	292	LF	$0.307	$3.38M	$132,895	$1.57M	100	0	98
7.12	7.50	15.0	1,394	1,908	400	LF	$0.261	$4.32M	$119,335	$1.84M	100	0	1,3
8.63	7.50	15.0	1,032	2,436	292	LF	$0.272	$3.95M	$132,488	$1.57M	100	0	98
7.12	4.47	20.0	819	2,340	429	LF	$0.286	$3.36M	$126,607	$1.39M	100	0	77
8.63	4.47	20.0	819	2,340	429	LF	$0.302	$3.12M	$126,640	$1.39M	100	0	77

Architecture: PV Array (kW)	Battery	Converter (kW)	Dispatch	Cost: COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	System: Ren Frac (%)	Total Fuel (L/yr)	PV Array: Capital Cost ($)	Production (kWh/yr)	Battery: Autonomy (hr)	Annual Throughput (kWh/yr)	Nomin
1,032	2,436	292	LF	$0.289	$3.63M	$132,826	$1.57M	100	0	980,732	1,536,344	14.0	434,801	2,438
1,068	2,376	295	LF	$0.289	$3.63M	$131,555	$1.59M	100	0	1,014,702	1,589,559	13.7	430,032	2,378
1,029	2,472	288	LF	$0.290	$3.65M	$133,658	$1.57M	100	0	977,174	1,530,771	14.3	437,417	2,474
1,021	2,472	299	LF	$0.290	$3.65M	$134,047	$1.57M	100	0	970,166	1,519,791	14.3	438,650	2,474
999	2,520	297	LF	$0.290	$3.65M	$135,007	$1.55M	100	0	948,929	1,486,523	14.5	441,891	2,522
1,047	2,472	287	LF	$0.291	$3.67M	$133,882	$1.59M	100	0	994,832	1,558,432	14.3	437,688	2,474

Fig. 28: Simulative Results of PV Mini-Grid Model (100%RE)



NominalDiscountRate (%)	ExpectedInflationRate (%)	Capacity Shortage (%)	Diesel Fuel Price ($/L)	150#G1 (kW)	150#G2 (kW)	Gener150 (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Tota (L
7.12	4.47	15.0	0.620	150	150		LF	$0.273	$3.77M	$235,986	$105,000	0	288,
8.63	4.47	15.0	0.620	150	150		LF	$0.274	$3.32M	$236,119	$105,000	0	288,
7.12	7.50	15.0	0.620	150	150		LF	$0.271	$5.00M	$235,527	$105,000	0	288,
8.63	7.50	15.0	0.620	150	150		LF	$0.272	$4.34M	$235,785	$105,000	0	288,
7.12	4.47	20.0	0.620	150	150		LF	$0.273	$3.77M	$235,986	$105,000	0	288,

150#G1 (kW)	150#G2 (kW)	Gener150 (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($/yr)	Fuel Cost ($/yr)	Hours	Produ (kW
150	150		LF	$0.273	$3.77M	$235,986	$105,000	0	288,347	8,760	729,061	220,261	17,520	136,562	2,526	227,53
150		150	LF	$0.273	$3.77M	$235,986	$105,000	0	288,347	8,760	729,061	220,261	17,520	136,562		
	150	150	LF	$0.273	$3.77M	$235,986	$105,000	0	288,347						8,760	729,06
150	150	150	LF	$0.277	$3.93M	$242,671	$157,500	0	296,870	8,760	729,209	220,300	17,520	136,586	2,526	213,00

Fig. 29: Simulative Results of Diesel Mini-Grid Model (100% NRE)

Table 1: Comparison of PV Mini-Grid (100% RE) and Diesel Mini-Grid (100% NRE)

Model	Design	Annual Production (kWh/yr)	COE ($)	Net Present Cost ($)	Operating Cost ($/ yr)	Initial Capital ($)	Diesel Fuel			
							Each (L/yr)	Total (L/y)	Each Cost ($/yr)	Total Cost ($/yr)
PVMG (100 % RE)	PV (1032 kW)	1536344	0.289	3.63 M	132826	1.57 M	-	-	-	-
	Battery (2436 kWh)	434801 (Through-put)								
	Converter (292 kW)	808240								
DMG (100 % NRE)	DG1 (150 kW)	729061	0.273 (at 0.62 $/L) 0.307 (at 0.72 $/L)	3.77 M (at 0.62 $/L) 4.85 M (at 0.72 $/L)	235986 (at 0.62 $/L) 264619 (at 0.72 $/L)	105000 105000	220261	288348	136562 (at 0.62 $/L) 158588 (at 0.72 $/L)	178776 (at 0.62 $/L) 207610 (at 0.72 $/L)
	DG2 (150 kW)	227535					68087		42214 (at 0.62 $/L) 49022 (at 0.72 $/L)	

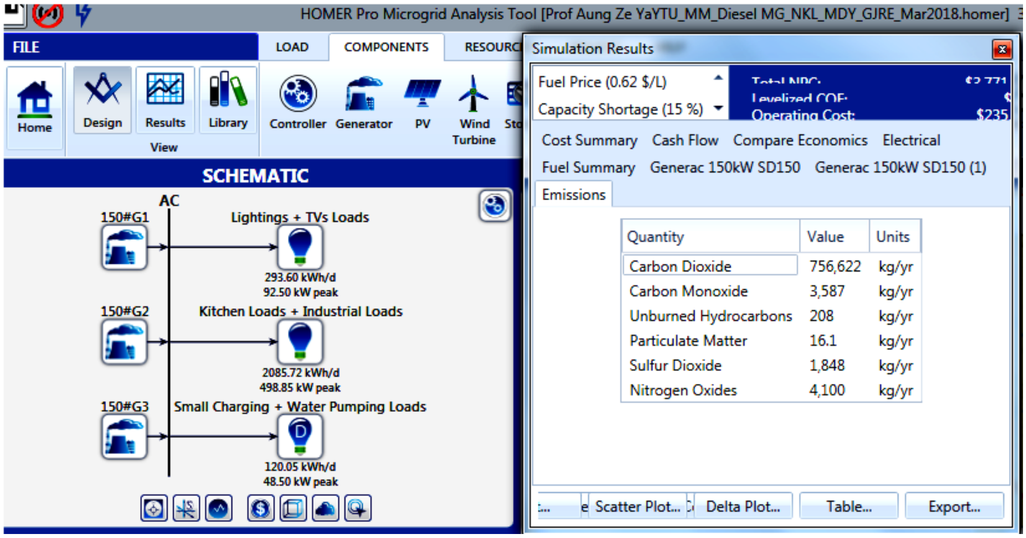


Fig. 30: Simulative Results of Emissions from Diesel Mini-Grid

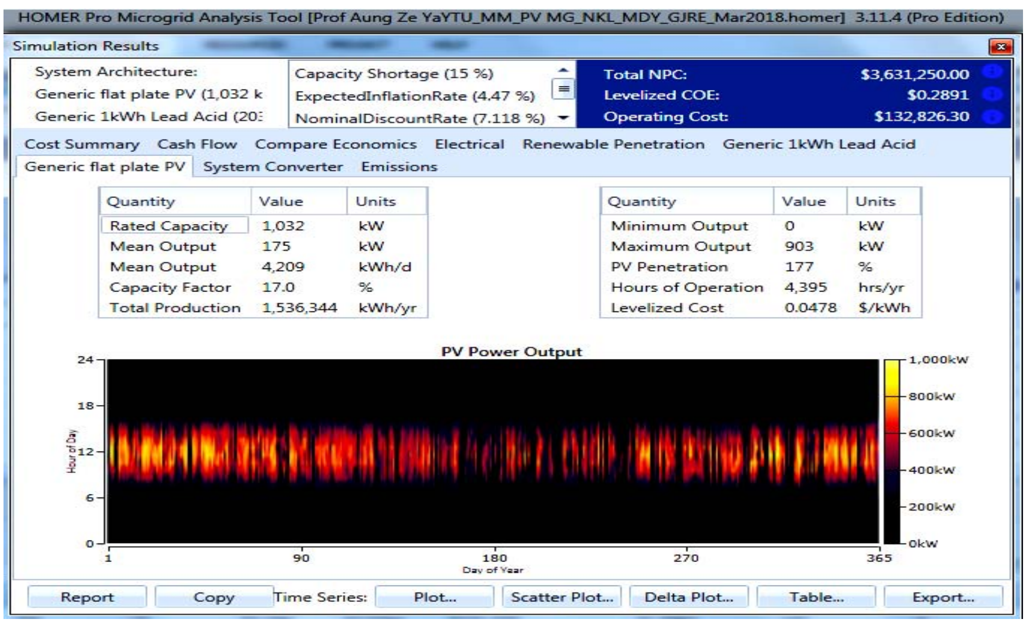


Fig. 31: Simulative Results of PV System

The comparison of the simulative results of PV Mini-Grid (100% RE) and Diesel Mini-Grid (100% NRE) mentioned in Table 1. Cost of Energy (COE) of PV Mini-Grid is slightly (0.016 $) higher than Diesel Mini-Grid at Diesel fuel price 0.62 $/L. However, COE of Diesel Mini-Grid at Diesel fuel price 0.72 $/L is 0.018 $ higher than the PV Mini-Grid. Again, the Initial capital cost of PV Mini-Grid is higher than Diesel Mini-Grid. Meanwhile, the operating cost of Diesel Mini-Grid is higher than PV Mini-Grid.

The main advantages of 100% RE model are there is no fuel consumption, no fuel cost, no worries about the increasing of fuel price and no emission. For 100% NRE model there is needed to consume the large fuel and fuel cost according to the fuel price as expressed in the right side of Table 1. Moreover, the Diesel Mini-Grid significantly contributes GHG emissions as reflected in the Fig. 30. Hence, it is evident that 100% RE model is the appropriate option from both economical and ecological point of views for long years.

b) Results of PV Mini-Grid (100% RE) Model

HOMER Pro evaluated the performance of PV Mini-Grid model with different kinds of results: Tabular and Graphical forms as espressed in Figs. 31 to 37.

i. *PV Results*

Simulative results of PV reflected in Fig. 31 are PV rated capacity 1032 kW, maximum output 903 kW, capacity factor 17%, production 1536344 kWh/yr, mean output 4209 kWh/day, and hours of operation 4395 hr/yr.

ii. *Battery Results*

Fig. 32 identified the simulative results of the Battery storage system. It has 2436 batteries with 203 strings in parallel and the bus voltage is 144 V. Its annual energy data is: input 484765 kWh/yr, output 388898 kWh/yr, losses 97081 kWh/yr, and throughput 434801. Its lifetime throughput is 194800 kWh, and the expected life is 4.48 years.

iii. *Converter Results*

Fig. 33 highlighted the Converter results as: capacity 292 kW, mean output 92.33 kW, minimum output 0 kW, maximum output 292 kW, capacity factor 31.5%, hours of operation 8594 hr/yr, energy output 808240 kWh/yr, energy input 850779 kWh/yr, and losses 42539 kWh/yr. All primary and deferrable loads considered as AC in the load profiles of village Nat Kan Lel. Therefore, in the waveform description of Fig. 33, there is no rectifier output.

iv. *Electrical Results*

Fig. 34 mentioned the Electrical results. These are: AC primary load 764563 kWh/yr (94.8%), deferrable load 43677 kWh/yr (5.4%), total consumption 808240 kWh/yr, excess electricity 589698 kWh/yr, unmet electric load 103891kWh/yr, capacity shortage 137542 kWh/yr, and maximum renewable penetration 10211.

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Fig. 32: Simulative Results of Battery Storage System

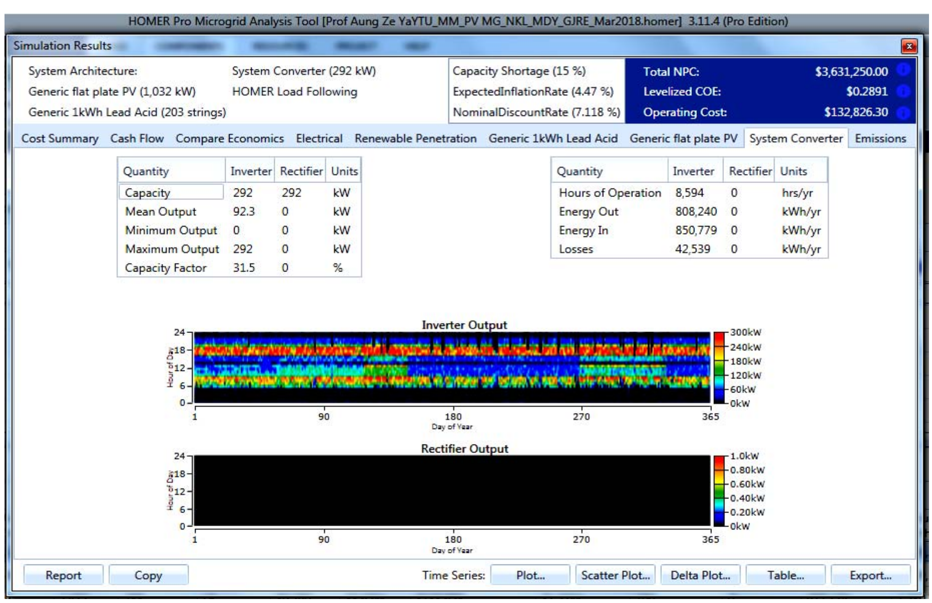

Fig. 33: Simulative Results of Converter

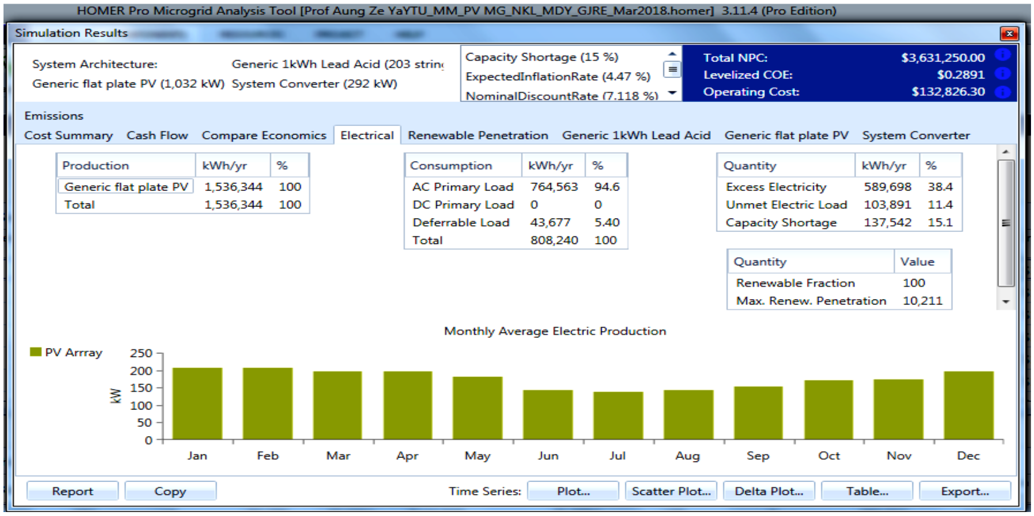

Fig. 34: Electrical Results of 100% RE Model

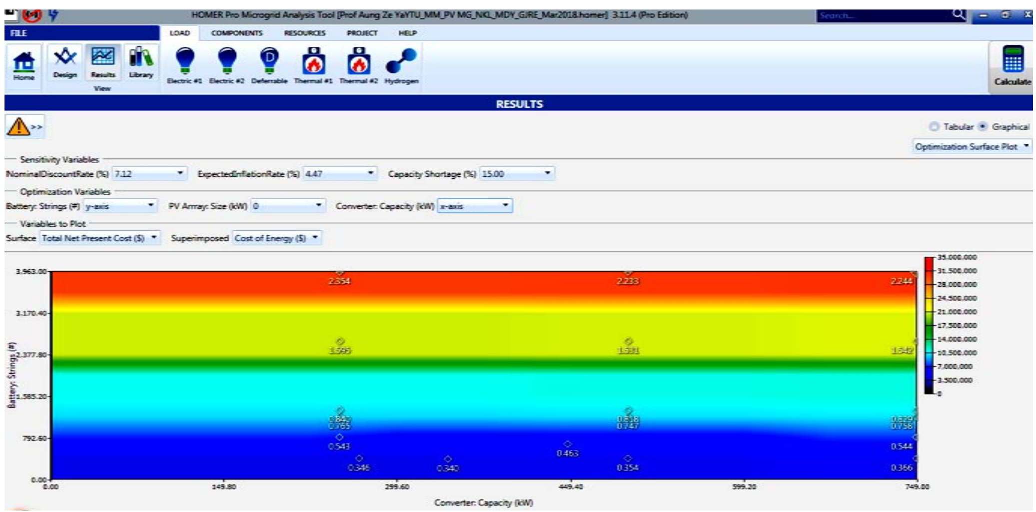

Fig. 35: Optimization Surface Plot of Battery Strings vs. Converter Capacity (kW) with Variables: Total NPC and COE

Fig. 36: The Battery Discharge vs. Total Electrical Load Served of Proposed PV Mini-Grid (100% RE)

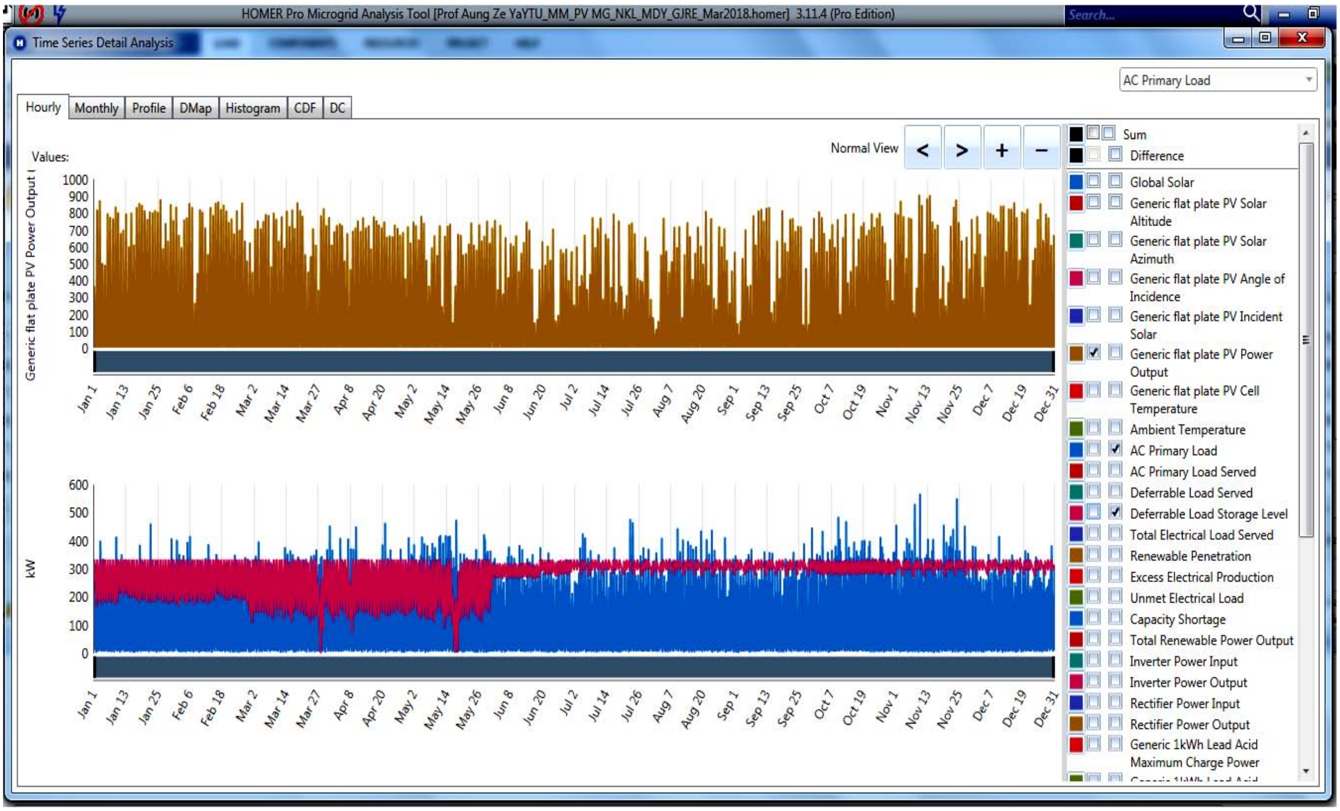

Fig. 37: Time Series Analysis of PV Power Output (Upper), Primary Load and Deferrable Load Storage Level (Lower)

VI. Conclusions

Rural Electrification is the one of the country's prioritized work because Rural Development is directly proportional to Rural Electrification. The Village Nat Kan Lel (Nagale) located near the National Park of Mount Popa, one of the legends of Myanmar. Hence, it is more important to conserve the forests as well as the Eco-system near it. Thus, the Novel Aim of this research is the development of 100% RE System.

The focused place is a big village blessed with high potential of Solar PV Energy as well as high soil quality of Agricultural business. At the present time, the inhabitants cannot access sufficient Electricity for 24 hours/day. In sub-session III, The existing problems defined, and the adverse impacts evaluated. At the current situation, there is CO_2 Emissions 4995 kg/yr from the Diesel fuel consumption 1893 L/yr. The fuelwood consumption is 6000 tons/yr and its cost is about 48000 $/yr. If the Diesel generation system install to fulfill all of the electrical demands, the fuel consumption will be 288348 L/yr, the fuel cost be 178776 $/yr for the fuel price 0.62 S/L and 207610 S/yr for 0.72 S/L. Also, there will be the significant amount of GHG Emissions: CO_2 756622 kg/yr, Carbon Monoxide 3587 kg/yr, Unburned Hydrocarbons 208 kg/yr, Particulate Matter 16.1 kg/yr, Sulfur Dioxide 1848 kg/yr and Nitrogen Oxides 4100 kg/yr. These issues can be solved by the implementation of the proposed PV Mini-Grid model. It composed of PV 1032 kW, Battery 2436 kWh, and Converter 292 kW. The annual productions are: PV 1536344 kWh/yr, Battery throughput 434801 kWh/yr, and Converter 808240 kWh/yr. COE is 0.289$.

This research work reflected how can improve Green Growth by PV Mini-Grid system. The simulative results are within the acceptable limits. The predicted Optimum model can fulfill the Electrical Energy needs of the whole village with 24-hour supply, uplift the quality of life of the villagers, and contribute to the SDGs. This research work can guide the strategic planning of the PV Mini-Grid system with linking the ground study as well as the application of the impressive tool, HOMER Pro.

Acknowledgements

First of all, the author expresses the deepest acknowledges to his father, U Sein Hla (Ret. Executive Electrical Engineer, Seven National Literatures Awarded Author, and the member of Central Executive Committee of Myanmar Writers Association), and also his mother, Daw Htway Lay for their infinite encouragements.

The author is much obliged to U Nyi Hla Nge (Ret. Deputy Minister of Ministry of Science and Technology, Chairman of Steering Committee for Centre of Excellence Technological Universities, and Vice Chairman of National Education Policy Commission) for his great leadership. The author deeply thanks to Dr. Myint Thein, Rector of Yangon Technological University (YTU) for his instruction. Also, the author is grateful to Dr. Khin Than Yu, Pro-Rector of Yangon Technological University for her guidance. Special thanks are due to Dr. Peter Lilienthal (CEO and Founder of HOMER Energy, USA) for sharing his invaluable experience. The author offers the heartfelt appreciations to JICA EEHE (Japan International Cooperation Agency, Enhancement of Engineering Higher Education) Project at YTU in Myanmar for covering the author charge.

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