

Green Improving by Autonomous PV Mini-Grid Model in

Prof. Aung Ze Ya¹ and Prof. Aung Ze Ya²

¹ Yangon Technological University

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Abstract

This research work verifies how can be able to gain Sustainability Benefits by improving Green Energy harvesting. The Goal is in line with the Goal No.7 of the world's 2030 Agenda: SDGs (Sustainable Development Goals) as well as Myanmar 2030 Agenda: NEP (National Electrification Planning towards Universal Access). The location of a focused village, Nat Kan Lel (Nagale) is near the beneath and National Park of Mount Popa in Kyaukpadaung Township, Mandalay Region. It has high demands due to 800 households with 4000 populations. This research explores the site experience, the problem statement and the evaluation of current demands for CO₂ Emissions. That village enriched high solar potential and blessed for a Novel Imagination of this work: change to Autonomous Photovoltaic Mini-Grid from existing 3 Diesel Mini-Grids. The thousands of models are simulated by a very powerful tool, HOMER Pro (version 3.11.4). New Diesel Mini- Grid (100

Index terms— autonomous photovoltaic mini-grid, central myanmar, HOMER pro, village nat kan lel, optimum.

1 INTRODUCTION

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].

Author: PhD, Post Doc, Honorary Professor and Honorary Doctor of Science, Professor of Department of Electrical Power Engineering, and Director of Department of Maintenance Engineering, Yangon Technological University (YTU), Myanmar. e-mails: dr.aungzeya010@gmail.com, profazzytum10@gmail.com 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 km², 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].

45 The key player of the implementation of the Off-Grid sector of the NEP is the Department of Rural
46 Development (DRD) under the Ministry of Agriculture, Livestock, and Irrigation (MOALI). DRD is boosting
47 Off-Grid Rural Electrification, and as a result, out of 63899 villages in total, 22911, nearly 36 % are electrified by
48 the end of FY 2016-2017. That amount is 10 % increased than FY 2015-2016 [5][6][7]. From [7], villages powered
49 by each type observed that 7507 by SHS (Solar Home System), 94 by PV Mini-Grid, 2769 by Diesel, and 1296
50 by Mini/Micro Hydro and 154 by Biomass/Biogas. Year 2018 F owardsays, the world is suffering impacts, Global
51 Warming and Climate Change, results of previous Green House Gas (GHG) emissions from the usages of the
52 fossil fuels. Renewables inherent possesses Sustainability due to the reliance upon infinitely available resources
53 that are naturally recharging with Zero fuel cost, Clean, Green, Eco-friendly and no or fewer emissions. To create
54 the better world for our next generations, Renewables promotion is the predominant backbone of all strategies
55 towards Sustainable Future of Mother Earth [1].

56 2 N b) State-of-the-Art

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

63 3 b) Interviews and Data Collection

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

70 4 d) SHS

71 At Village Nat Kan Lel, SHS with conventionally ground-mounted and rooftop structures found. Fig. ?? (a the
72 battery within the operation limits and its lifetime. Also, it contributes the substantial cost factor, and there
73 may be undesirable hazards as a consequence of the overcharging of the battery in the tropical areas. Thus, it is
74 needed to aware the villagers to use it.

75 III.

76 5 PROBLEMS AND DEMANDS a) Generation Systems

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

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

87 6 b) Distribution System and Loads

88 Currently, the villagers are commonly using the lightings as 2 ft FL, 26 W CFL (Compact Fluorescent Lamp),
89 rechargeable DVD player, 21" TV and mobile phone charger. Due to the study in [16], it is evident that there
90 are multiple negative impacts of CFL as shown in Fig. 12. Also, there are harmonics problems, high reactive
91 power demands, and power factor problem by using FL and CFL. Due to evaluation in [17], the aggregated sum
92 of the injected harmonics by FLs and CFLs in residential houses and commercial buildings contributes to the
93 increased current distortion within distribution systems.

94 From Fig. 12, LEDs are more environmentally friendly, cost-effective and Energy efficient than CFL and
95 incandescent lights [16]. From Fig. 1(b), the conductor is Zinc. The conductivity of Zinc is lower than others
96 [18]. Thus, it should be changed to conducting lines, also other design issues.

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

100 The rice and curry are daily main food as well as traditional donation food in Myanmar, especially at the
101 village. Consequently, the villagers always apply the firewood for cooking. Also, they use it for making Myanmar
102 traditional snacks and the tea. Fig. ??4 reveals how the villagers are cooking at the focused village. Consequently,
103 the negative impacts are:

104 **7 i. Deforestation towards Climate Change**

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

109 ii.
110 GHG Emissions towards Global Warming CO₂ Emissions from the burning wood is 109.6 kg CO₂ per GJ
111 [??19]. Other chemicals are produced, including nitrogen dioxide; 200 g of CO₂ equivalent per kg of wood burnt,
112 the gas is 300 times more potent as a greenhouse gas than CO₂ and lasts 120 years in the atmosphere. Methane
113 produced (70 g of CO₂ equivalent per kg of wood) -21 times more potent than CO₂. Carbon monoxide is
114 also in large amounts. Overall, although figures vary depending on a multitude of factors, there is no doubt that
115 wood burning is contributing to Global Warming [20]. Due to [27], the Emissions from fuelwood consumption at
116 that village calculated as nearly 8981128 kg CO₂ /year.

117 iii.

118 **8 Health Problems from the Wood Burning**

119 The health implications of wood burning derive from the emissions which contain carbon monoxide, nitrogen
120 dioxide, and particulates, as well as other noxious gases [20]. More than four million people die each year from
121 illnesses attributable to indoor air pollution from cooking with traditional biomass and inefficient cook-stoves.
122 For the one billion people who depend on health facilities in remote and rural areas that presently lack electricity
123 [9, ??1].

124 iv. Cost for Fuelwood According to the interviews' results, the monthly fuelwood per household is 5 \$. Then,
125 the total cost for the whole village is 48000 \$ per year. That amount calculated for the fuelwood usage in the
126 households. It is sure that there is more cost of the fuelwood combination with the fuelwood cost for donation
127 ceremonies. Due to site study, there is easy to be fire hazard from the combinational effects of conventional
128 firewood cooking and the constructional materials of the rural house. It located in the Central Dry Zone Area
129 that is also easy to be the fire hazard due to its weather condition. Moreover, there is Diesel fuel storage for
130 Firewood Rural Home Wall (Easy to be Fire Hazard)

131 **9 d) Vital Needs of the Water**

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

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

140 It observed that there are seven water tubewells (including one well at RHC) in that village to fulfill the water
141 needs. Among these tube-wells, the one tubewell is supported by the Government in June 2010. That tube-well
142 was deepest (600 ft depth, 4 inches diameter, 2200 gallon per hour) and its water has pH (power of Hydrogen)
143 7.5. Humans have a higher tolerance for pH levels, and drinkable levels range from 4-11 [22]. Hence, the villagers
144 obtained the drinking water from it. There is 5000 gal water storage tank at that tube-well. The others are 300
145 depths with 3 inches diameters. The tube-well of RHC has 5000 gal water storage tank, and the others have
146 their tanks around 4000 gal storage. The village has other rain water storage facilities at the monasteries and
147 households as reflected in Figs. 15 and 16.

148 **10 e) Energy Needs for Small Enterprise**

149 During the ground visit, it saw that there are two categories of the industrial loads dealt with the small enterprises.
150 The former is needed for daily use as revealed in Figs. 17

11 Coordinates of Village

12 Roofs of Houses 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, 13]. 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%.

13 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/m² (average daily total up to 5.2 kWh/m²) 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. 11 are relevant with the map data of Fig. 10 [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 m² 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.

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. 12. Then, there is only one left, PV Mini-grid to create zero emissions power generation.

14 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.

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.

15 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.

16 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 \$/year. The advanced input is the ground reflectance

17 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.

204 Then, the optimum designs are achieved with the Tabular results of different portions (architecture, cost,
205 system, and each component) as mentioned in Figs. 28 and 29. The upper table is Sensitivity results, and the
206 lower one is Optimization results. The optimum model is at the first row of these tables. The comparison of the
207 simulative results of PV Mini-Grid (100% RE) and Diesel Mini-Grid (100% NRE) mentioned in Table 1. Cost of
208 Energy (COE) of PV Mini-Grid is slightly (0.016 \$) higher than Diesel Mini-Grid at Diesel fuel price 0.62 \$/L.
209 However, COE of Diesel Mini-Grid at Diesel fuel price 0.72 \$/L is 0.018 \$ higher than the PV Mini-Grid. Again,
210 the Initial capital cost of PV Mini-Grid is higher than Diesel Mini-Grid. Meanwhile, the operating cost of Diesel
211 Mini-Grid is higher than PV Mini-Grid.

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

217 **18 b) Results of PV Mini-Grid (100% RE) Model**

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

220 **19 i. PV Results**

221 Simulative results of PV reflected in Fig. 31 are PV rated capacity 1032 kW, maximum output 903 kW, ii.

222 **20 Battery Results**

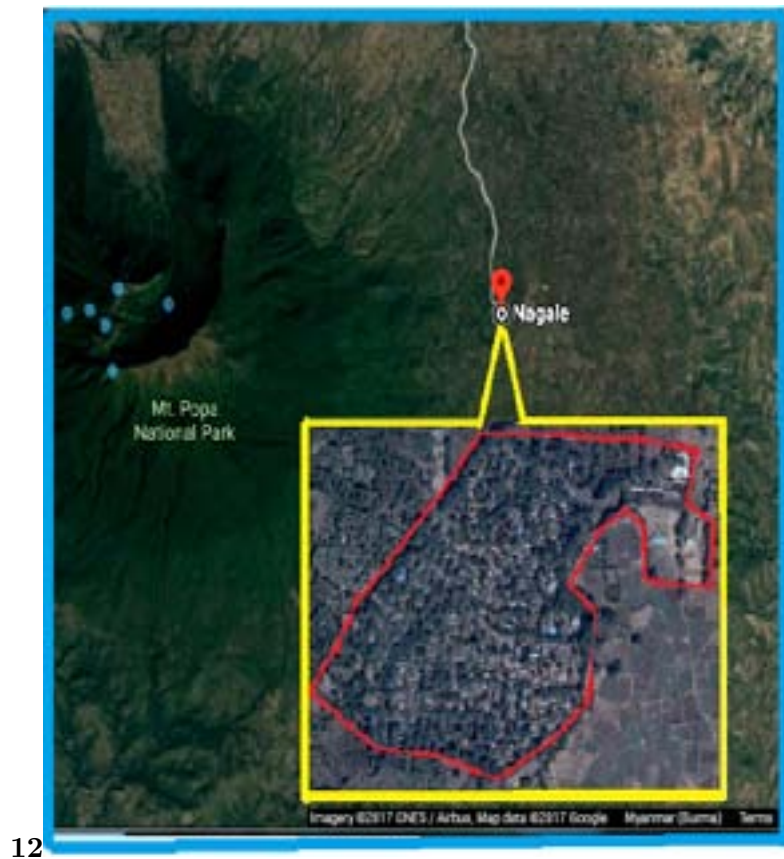
223 Fig. 32 identified the simulative results of the Battery storage system. It has 2436 batteries with 203 strings in
224 parallel and the bus voltage is 144 V. Its annual energy data is: input 484765 kWh/yr, output 388898 kWh/yr,
225 losses 97081 kWh/yr, and throughput 434801. Its lifetime throughput is 194800 kWh, and the expected life is
226 4.48 years.

227 **21 iii. Converter Results**

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

233 **22 Electrical Results**

234 Fig. 34 mentioned the Electrical results. These are: AC primary load 764563 kWh/yr (94.8%), deferrable load
235 43677 kWh/yr (5.4%), total consumption 808240 kWh/yr, excess electricity 589698 kWh/yr, unmet electric load
236 103891kWh/yr, capacity shortage 137542 kWh/yr, and maximum renewable penetration 10211. The focused
237 place is a big village blessed with high potential of Solar PV Energy as well as high soil quality of Agricultural
238 business. At the present time, the inhabitants cannot access sufficient Electricity for 24 hours/day. In sub-session
239 III, The existing problems defined, and the adverse impacts evaluated. At the current situation, there is CO 2
240 Emissions 4995 kg/yr from the Diesel fuel consumption 1893 L/yr. The fuelwood consumption is 6000 tons/yr
241 and its cost is about 48000 \$/yr. If the Diesel generation system install to fulfill all of the electrical demands, the
242 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
243 for 0.72 S/L. Also, there will be the significant amount of GHG Emissions: This research work reflected how
244 can improve Green Growth by PV Mini-Grid system. The simulative results are within the acceptable limits.
245 The predicted Optimum model can fulfill the Electrical Energy needs of the whole village with 24-hour supply,
246 uplift the quality of life of the villagers, and contribute to the SDGs. This research work can guide the strategic
247 planning of the PV Mini-Grid system with linking the ground study as well as the application of the impressive
248 tool, HOMER Pro.



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Figure 1: Fig. 1 :Fig. 2 :



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Figure 2: Fig. 3 :



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Figure 3: Fig. 4 :Fig. 5 :



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Figure 4: Fig. 6 :



Figure 5: Fig. 7 :

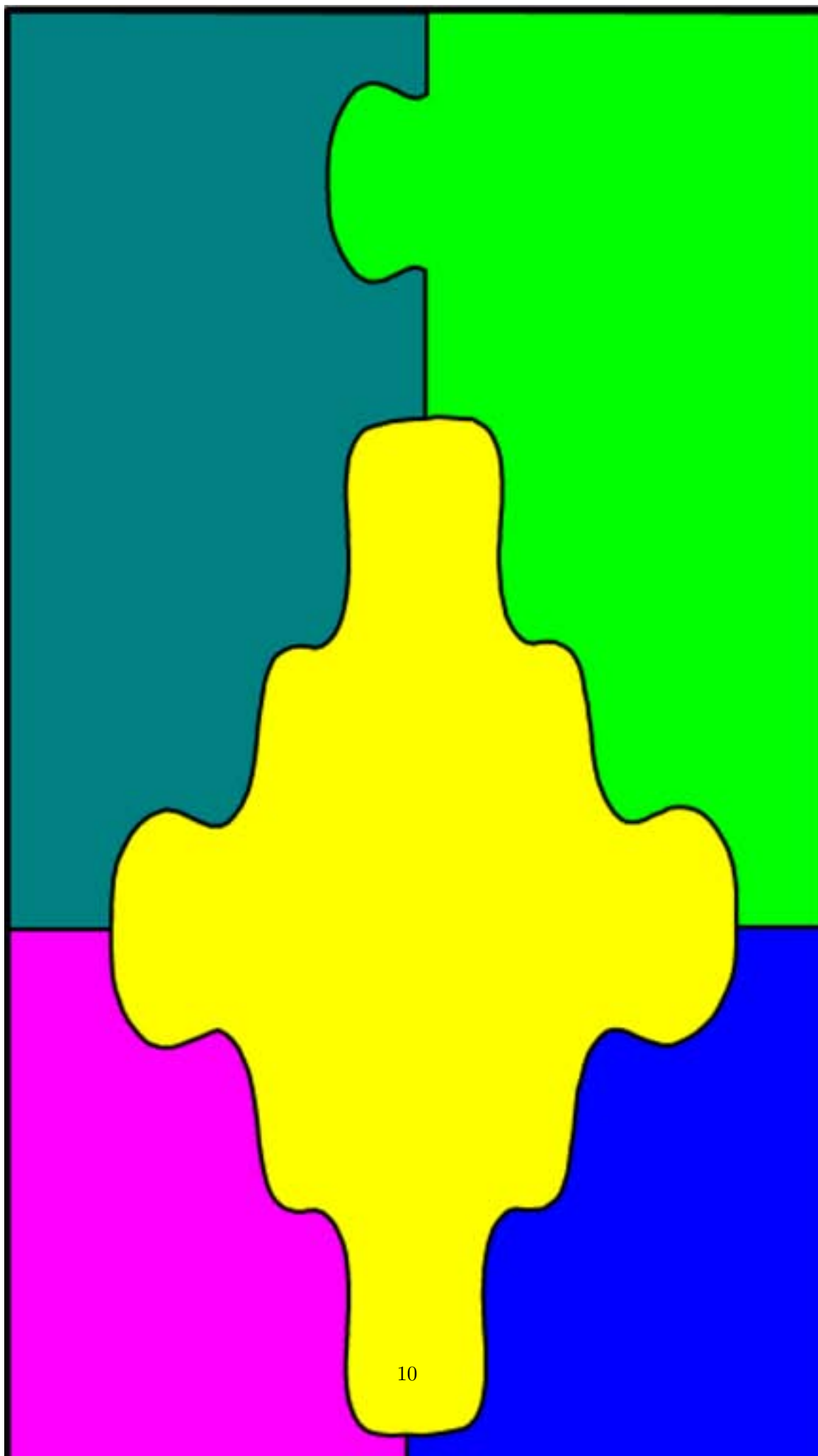




Figure 7:



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Figure 8: Fig. 10 :



Figure 9:



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Figure 10: F Fig. 16 : Fig. 17 : F



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Figure 11: Fig. 18 :



Figure 12: F



Figure 13: Fig. 21 :Fig. 22 :

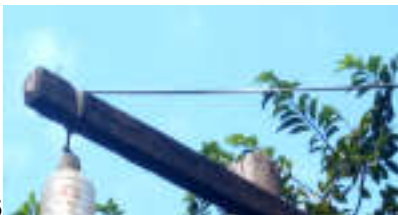


Figure 14:



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Figure 15: Fig. 23 :



2426

Figure 16: Fig. 24 :Fig. 26 :



Figure 17: Fig. 27 :F



Figure 18: Fig. 29 :



Figure 19: Fig. 31 :



Figure 20: Fig. 30 :



Figure 21: Fig. 32 :



34

Figure 22: Fig. 34 :



35

Figure 23: Fig. 35 :

Figure 24:

1

(100 % PV MG RE)	(1032 kW) PV Battery (2436 kWh) Converter (292 kW)	1536344	0.289	3.63 M	132826	1.57 M	-	-	-	-
D MG (100 % NRE)	DG1 (150 kW)	729061	0.273	3.77 M	235986	105000	20261	288348	136562	17
			(at 0.62 \$/L)	(at 0.62 \$/L)	(at 0.62 \$/L)				(at 0.62 \$/L)	(a 0. \$/
			0.307 (at 0.72 \$/L)	4.85 M (at 0.72 \$/L)	264619 (at 0.72 \$/L)	105000			158588 (at 0.72 \$/L)	20 (a 0. \$/
	DG2 (150 kW)	227535	\$/L)	\$/L)	\$/L)	68087			42214 (at 0.62 \$/L) 49022 (at 0.72 \$/L)	\$/

Figure 25: Table 1 :

Figure 26: F

.1 ACKNOWLEDGEMENTS

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