PV-Biodiesel Hybrid-DC Grid for Chiang Mai World Green City Community Model

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Abstract—The main objective of this research is to design a stable, economic efficient and affordable stand-alone DC community grid system with 264-297 VDC from hybrid biodiesel-PV power generation. The main components of the system were 25.5 kW PV panels, 40 kW biodiesel generator, a solar charger, 44 central batteries, 4 booster batteries (installed in each building), and underground DC cables. The community consisted of 4 residential housing, 1 office, 1 coffee shop, 1 minimart, and 1 restaurant. The results showed that, the integration of batteries, PV and biodiesel power generation as power supply was sufficient for load power of stand-alone DC community grid. Moreover, stand-alone DC grid system with modified DC appliances is more cost-effective in economics than stand-alone AC grid system. That would be practical for rural community.

Keywords - DC grid, community power, stand-alone PV, DC appliances

I. INTRODUCTION

The stand-alone power system is the off-grid system which is not connected with the distribution system of the electricity authority [1-7]. The system could be used in both of the areas where the distribution system can be accessed or in the remote areas without the access to electricity [2, 6]. The stand-alone system is basically a system that uses with the electrical load of alternating current (AC) [2-6]. The main equipment includes photovoltaic (PV), charge controller, inverter and batteries [1, 2, 5]. However, using this system, there are problems with charge controller and inverter due to many factors, including deterioration of the devices, inappropriate uses, hot and humid weather and insects making nest in the devices. These cause damage to the equipment and the change of new devices is expensive. In addition, DC-AC conversion could also produce power loss generated by the inverters [8-10]. DC grid is considered as excellent alternative for solving these problems because it does not require inverter to convert DC to AC power. The power produced by renewable energy could distribute to the community grid directly [8, 11-17]. Moreover, many appliances such as computers, mobile phone charger, LED lighting and electric vehicles run on DC power while world's electricity produces AC power. Conversion of AC to DC power also causes energy loss [9, 10, 18]. Therefore, using the DC appliances is one way to reduce the use of the inverter and also reduced power loss because they could use power supplied from renewable energy such as PV directly [15, 16, 19, 20].

However, there is no clear information about the power system supplying the direct current (DC) for the community in Thailand. The authors decided to develop the low-voltage DC grid system for communities in remote areas with the aim to achieve the sustainable use and the stability of electricity and to be the innovation for communities in remote areas without access to electricity in the future. Consequently, Chiang Mai World Green City community model was developed with the goal to be the model community to integrate between biodiesel and PV energy generations with DC grid.

Figure 1. Chiang Mai World Green City community model

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Figure 2. Coffee shop (a), minimart (b), restaurant (c), New house (d), office (e), A-Frame house (f), Green cottage (g), Box house (h) and Diamond house (i) in Chiang Mai World Green City community model

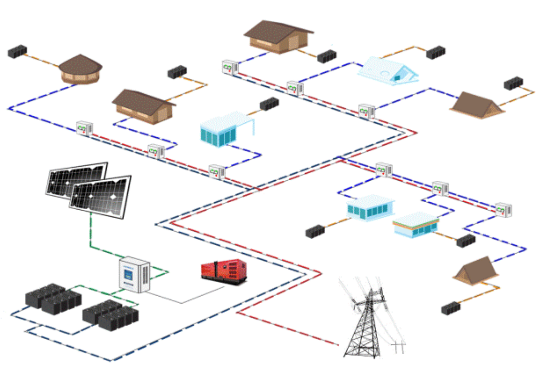

Figure 3. DC grid system concept design

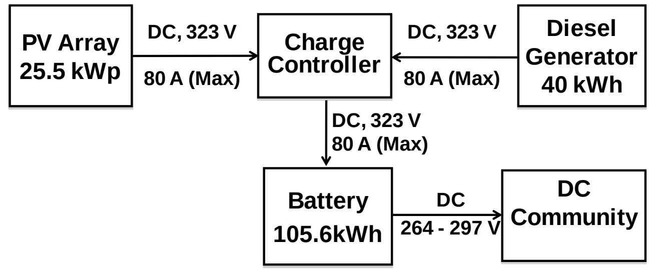

Figure 4. DC power storage and a DC power supply

II. Research Methodology

A. Characteristic Loads

In this work, stand-alone DC grid was studied in Chiang Mai World Green City (CWGC) community model, as shown in Fig. 1, that is located in Asian Development College for Community Economy and Technology (adiCET), Chiang Mai Rajabhat University, Mae Rim District, Chiang Mai. From Fig. 2, there are 9 units building including 5 houses, 1 office, 1 minimart, 1 restaurant and 1 coffee shop. DC appliances consisted of air conditioners, refrigerators, televisions, microwaves, rice cookers, water heaters, cell phone chargers, computers, Compact fluorescent light bulbs, Halogen light bulbs, Incandescent light bulbs, LED light bulbs and DC plugs. All the electrical devices was modified as DC appliances and set for 264-297 VDC usage.

B. DC Grid System Design

DC grid system concept design is represented in Fig. 3. The main components of the grid system are PV generator, biodiesel generator, control system, power grid, and the characteristic loads. There is not an inverter in this design. The system has DC power storage and a DC power supply, as shown in Fig. 4, which is composed of 25 kWp PV panels (KANEKA, LEC5048, thin film silicon), 40 kWh biodiesel generator (BOLING CHAIYOUJI, BLR4105ZD), battery charger (LEONICS, SCP240120) and 105.6 kWh central batteries and 2.4 kWh booster batteries (BSB, DB 12-200, 12 V, 200 Ah).

The 25.5 kWp PV module produces 323 VDC. Therefore, the 40 kWh biodiesel generator also was set up to produce 323 VDC to the DC grid. The PV generator comprises of 510 amorphous PV modules 25.5 kWp. The module specification is Pmax = 50 W, Voc = 85.7 V, Isc = 1.15 A, VPM = 64.6 V, and IPM= 0.784 A. The amorphous panels were chosen due to the affordability and the PV could produce electricity at a broader spectrum than the crystallize type [21-23]. The PV panels were installed facing south integrating with the surrounding landscape. Part of the PV modules was installed on the rooftop of the car park. The ground mounted PV yielded 24 kW via 6 combine modules of 4 kW each. For each combine module, 5 panels were connected in series and 16 modules were connected in parallel to which the voltage would be 323 V and current 12.55 A. The rooftop PV of the car park had 5 panels connected in series and 6 modules connected in parallel – 1.5 kW in total. Thus, the combination of 7 combiner modules yielded 25.5 kWp.

The storage system, central batteries, has 22 batteries in series to achieve 264 VDC and 2 parallel to obtain the capacity of 105.6 kWh. The system was designed to charge the batteries using power from PV panels and control the level of DC voltage for charging the batteries automatically. This will prevent damages to the batteries that caused by over voltage and over current charging. In addition booster batteries were also installed in each building which consisting of 4 batteries in series to achieve 54 VDC-2.4 kWh in total. Booster batteries could improve building stability when voltage drop occur. Therefore, all electric devices could be operated smoothly.

System monitoring units (SMU) were also installed and used to monitor and record parameters of the system e.g. the amount of charging energy, the amount of discharging energy, solar irradiance, PV module temperature, ambient temperature, etc. The recorded data can be retrieved later and used for analyzing the system performance.

TABLE I SYSTEM OPERATION MODE

Central batteries voltage (VDC)	Mode	System operation
297 – 260	Full	DC use directly from central batteries bank
260 – 250	Batteries boosting	DC from batteries bank (260 VDC) & booster batteries (54 VDC)
250 – 242	Biodiesel generator start	Biodiesel generator start - Charge batteries bank - Charge booster batteries
Below 242	Batteries dead	Automatically switch to AC

TABLE II MODIFIED DC APPLIANCES OPERATION TEST

DC Appliances	Evaluation parameters	
	Operation	Short-circuit
Air conditioners	✓	x
Refrigerators	✓	x
Televisions	✓	x
Water heaters	✓	x
Cell phone chargers	✓	x
Computers	✓	x
Compact fluorescent light bulbs	✓	x
Halogen light bulbs	✓	x
Incandescent light bulbs	✓	x
LED light bulbs	✓	x

C. *System Operation Mode*

The system operation mode was designed to control the power supplied from PV, biodiesel generator, AC utility grid and batteries. For the software design concept, the load profile was mainly using DC power from renewable. The PV was mainly used for batteries charging during the daytime according to the solar radiation curve. If more power is needed, the biodiesel generator would be used. The power from biodiesel was used to maintain power availability and stability of the load profile. During nighttime, batteries discharge would provide power while the biodiesel generator will be used minimally. However, in the case of insufficient DC power from renewable, AC power from university utility grid would be used as the backup. The order of system operation was designed according to the voltage of central batteries as shown in Table 1. When the voltage of central batteries was in the range of 297-260 VDC, DC would be used directly from central batteries bank. After the system was operated, central batteries voltage decrease continuously. Batteries boosting mode would be started when central batteries voltage drops below 260 VDC. In this mode, DC from central batteries (260 VDC) and booster batteries (54 VDC) would be used. If central batteries voltage drops below 250 VDC, biodiesel generator would be operated for batteries charging. Lastly, when central batteries voltage drops below 242 VDC, the system would be automatically switched to utility AC mode.

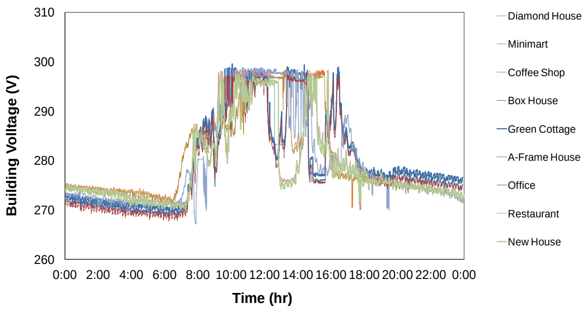

Figure 5. DC voltage supply to the buildings of the community

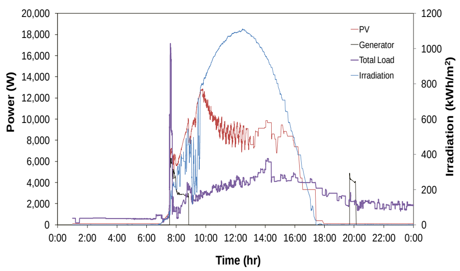

Figure 6. Relationship between solar radiation, total load, and electric power generated from PV and biodiesel generator for 1 day

D. *Economic evaluation*

Economic evaluation was focused on the feasibility in implementing the DC power grid to the local community. The analysis determine the financial and economic index for this the study such as net present value, benefit-cost ratio, internal rate of return, payback period and cost of energy. The conditions for the economic analysis were as follows:

- Discount Rate = 8.5%
- Project period = 20 years
- Total power generation decrease 1% each year

In this research, DC power was used to reduce energy losses and electricity cost of the community. Therefore, 2 systems were compared including 1) Stand-alone DC grid 25.5 kW system with modified DC appliances and 2) Stand-alone AC grid 25.5 kW system with inverter.

III. Results and Discussion

A. *Modified DC Appliances Operation Test*

In this work, modified DC appliances operation test was performed. This tested the safety of the DC system by short-circuiting 264VDC system to determine the fail-safe of the system and if the short circuit can cause damage to the DC appliances and other part of the DC grid. The short circuit test was performed in each building. The over load testing was performed by creating load demand greater than the power supply to determine the system and DC appliances operation and efficiency. The test was performed in each building. From Table 2, the result shows that all DC appliances could be operated well and there was no arc or short-circuiting in the DC power line or DC appliances.

B. *System Operation Evaluation*

Fig. 5 shows the DC voltage supply to the building of the community. In the period from 7.00 a.m. until 5.00 p.m., there was solar radiation that let PV generated power and charged central batteries. These resulted in the increasing of central batteries voltage. Therefore, DC voltage supply to the building of the community also increased significantly from 278 to 297 VDC. Although DC voltage supply to the buildings increased up to 13% during day time, DC appliances could be operated smoothly due to the voltage of 278–297 VDC are in the appropriate range for DC appliances operation. Furthermore, DC voltage supply to buildings from 5.00 p.m. until 7.00 a.m. of the next day gradually decreased from 278–270 VDC. During this range, DC appliances also could be operated smoothly. It could be noticed that DC voltage supply to all the buildings of the community were found to be higher than 270 VDC. For the reason that there were booster batteries (2.4 kWh–54 VDC) installed in each building, booster batteries could increase voltage supply to the building in order to stabilize the system operation.

TABLE III Economic Evaluation

Project Indicator	Stand-alone DC grid 25.5 kW with modified DC appliances	Stand-alone AC grid 25.5 kW with inverter
Present value of costs (PVC)	3,905,395.73 Baht	4,857,030.62 Baht
Present value of Benefits (PVB)	3,376,709.97 Baht	3,039,081.41 Baht
Net Present Value (NPV)	-528,685.76 Baht	-1,817,949.20 Baht
Benefit-Cost Ratio (BCR)	0.86	0.63
Internal Rate of Return (IRR)	6.19%	3.85%
Payback period (PB)	16 years	> 20 years
Cost of Energy (COE)	6.74 Baht/unit	9.31 Baht/unit

Fig. 6 shows the relationship between solar radiation, total load, and electric power generated from PV and biodiesel generator for 1 day. It was found that, after 7 a.m., PV and biodiesel power generation started to charge central batteries. From 9.00 a.m., when central batteries voltage increased more than 250 VDC, biodiesel generator stopped. During the day, PV power generation increased continuously corresponding to load power consumption and batteries charging. Due to low demand of load power, power generation reduced after 10 a.m. After 6 p.m., without solar radiation, PV power could not generate. Therefore, central batteries were discharged to supply load power. During 7.40 - 8.05 p.m., biodiesel power generation started to charge central batteries. After that, DC grid system provides power from central batteries discharging until morning. The results showed that, the integration of batteries, PV and biodiesel power generation as power supply was sufficient for load power of stand-alone DC community grid.

C. Economic evaluation

For the economic evaluation, stand-alone DC grid 25.5 kW system with modified DC appliances and stand-alone AC grid 25.5 kW system with inverter were compared. The benefit analysis was based on the comparison of the electricity production from diesel fuel (12 Baht/unit). From Table 3, present value of costs (PVC) for DC grid and AC grid were 3,905,395.75 and 4,855,030.62 Baht, respectively. The result showed that AC grid required higher cost for building up the project more than DC grid. AC grid also obtained lower present value of benefits (PVB) of 3,039,081.41 Baht compared to DC grid of 3,376,709.97 Baht. Moreover, benefit cost ratio (BCR) of DC grid was 0.86 which was higher than AC grid of 0.63. While payback period (PB) for DC grid system was 16 years, AC grid system was over 20 years. In the case of the comparison between using DC grid, AC grid and biodiesel generator as power supply, cost of energy (COE) could be found to be 6.74, 9.31 and 12 Baht/unit respectively.

From the economic evaluation, it could be concluded that stand-alone DC grid 25.5 kW system with modified DC appliances is more cost-effective in economics than stand-alone AC grid 25.5 kW system with inverter. When compared to conventional technology that using biodiesel generator as power supply, stand-alone DC grid with modified DC appliances could be considered as appropriate way for the remote areas because they could reduce cost of energy from 12 to 6.74 Baht/unit. Therefore, it could enhance the quality of life in the community.

IV. Conclusion and Suggestions

This work proposed an innovative concept of generating electricity from PV and biodiesel generator and distributing to the community as 264-297 VDC without having to convert to AC. There were central batteries used as power storage. Additionally, booster batteries were also installed in each building to stabilize the operation of appliances. This prototype is called Chiang Mai World Green City (CWGC) community model DC grid.

All the buildings of the CWGC community were modified to be able to operate on the 264 – 297 VDC. In addition, the biodiesel generator was also integrated to the community power system making the Smart Community a true test-bed for hybrid community DC microgrid system. Operating with DC power, the load profiles for the appliances are quite stable representing the DC power quality. The modified appliances could be used efficiently with community decentralized PV-biodiesel hybrid systems with direct-DC distribution.

The electricity distribution with 264-297 VDC would eliminate issues with high cost of inverters, the loss of energy during the conversion steps and in the large distribution cables. DC systems also create less electromagnetic interference than AC systems. Moreover, from economic evaluation, stand-alone DC grid system with modified DC appliances is more cost-effective in economics than stand-alone AC grid system. The low cost system is suitable for the small community with restricted income.

From this work, the small community will have a guideline of how to transition from an AC based community into a DC based community. The outcome of this research can be applicable to the rural community with simple household appliances. It is with high hoped that through creating changes that meet the fundamental needs of people’s everyday life can then encourage community development and improve the overall quality of life and sustainability of the community. In conclusion, we strongly believe that DC grid with DC appliances is the innovation which is appropriate for rural communities in the future.

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