OPERATIONAL EXPENDITURE COST ANALYSIS FOR SMALL SCALE PROTON EXCHANGE MEMBRANE FUEL CELL

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OPERATIONAL EXPENDITURE COST ANALYSIS FOR SMALL SCALE PROTON EXCHANGE MEMBRANE FUEL CELL

AIDA BINTI DEN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

Malaysia-Japan International Institute of Technology
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MARCH 2019

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DEDICATION

To all people around me who are very supportive.

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ABSTRACT

Rural areas in Sabah have problems connecting to the national grid due to their geographical conditions. Hence, the Proton Exchange Membrane Fuel Cell (PEMFC) off-grid power system using hydrogen from the Ocean Thermal Energy Conversion (OTEC) is recommended. This study carried out calculations for the operational cost using hydrogen from OTEC to serve as baseline for the implementation of PEMFC off-grid power system. Performance of small scale off-grid power system using hydrogen has been analysed and proposed to overcome this problem. To demonstrate the off-grid system, 1 kW PEMFC from the Horizon Fuel Cell Company model H-1000XP was used. Direct Current (DC) output from PEMFC was regulated using DC/DC converter prior supply to the DC/AC inverter. DC voltage was inverted to Alternate Current (AC) by using 1 kW pure sine wave inverter from Swipower Company and supplied to the customized 1 kW of bulb loads. This system shows that PEMFC was able to deliver power of up to 400 W and the efficiency was 40%. The operational cost for 1 kW PEMFC using hydrogen from OTEC for 25 years was calculated as RM316,066,410. Data of the existing diesel generator capacity in Felda Sahabat, Sabah was used as a guideline to propose the PEMFC capacity for Felda Sahabat. The total diesel generator capacity in Felda Sahabat was 10,785 kW. Estimation for suitable electrical power plant capacity for Felda Sahabat was 80% from the total diesel generator capacity which was recorded as 8,628 kW. In order to obtain net power of 8,628 kW, the idea was to develop PEMFC in modular mode whereas each modular power rated was 100 kW. Electrical specification for 100 kW was between 1.2 kV to 1.44 kV for voltage and 0 A to 70 A for current, respectively. A total of 216 units of 100 kW modular PEMFC were required to deliver net power of 8,628 kW using 40% efficiency of PEMFC off-grid power system estimation.

ABSTRAK

Kawasan pedalaman di Sabah mempunyai masalah untuk dihubungkan dengan grid nasional kerana keadaan geografinya. Justeru, penjana eletrik Sel Bahan Api Membran Pertukaran Proton (PEMFC) yang tidak bersambung kepada grid dan menggunakan hidrogen dari Sistem Penukaran Tenaga Haba Lautan (OTEC) adalah disyorkan. Kajian ini menjalankan pengiraan kos operasi sistem PEMFC dengan menggunakan sumber hidrogen dari OTEC untuk menjadi asas bagi perlaksanaan sistem PEMFC. Janakuasa elektrik pada skala kecil bagi sistem yang tidak bersambung kepada grid yang menggunakan hidrogen telah dianalisa dan dicadangkan untuk mengatasi masalah ini. Untuk pengujian sistem ini, 1 kW PEMFC model H-1000XP dari Syarikat Horizon Fuel Cell telah digunakan. Arus terus (DC) dari PEMFC dikawal dengan menggunakan penukar arus DC/DC sebelum dibekalkan kepada penyongsang arus DC/AC. Arus terus (DC) ditukarkan kepada arus ulang alik (AC) menggunakan penyongsang arus dari Syarikat Swipower dan dihantar kepada beban lampu sebanyak 1 kW. Sistem ini menunjukkan bahawa PEMFC mampu membekalkan elektrik sehingga 400 W dan kecekapannya adalah 40%. Kos perbelanjaan operasi untuk 1 kW PEMFC menggunakan sumber hidrogen dari OTEC selama 25 tahun telah dikira dan hasilnya adalah RM316,066,410. Data mengenai kapasiti penjana diesel sedia ada di Felda Sahabat, Sabah telah dikumpulkan sebagai garis panduan untuk mencadangkan kapasiti PEMFC bagi Felda Sahabat. Kapasiti penjana diesel di Felda Sahabat adalah 10,785 kW. Anggaran kapasiti loji kuasa elektrik yang sesuai untuk Felda Sahabat adalah 80% dari jumlah kapasiti penjana diesel iaitu 8,628 kW. Untuk mendapatkan kuasa bersih 8,628 kW, PEMFC dibangunkan dalam bentuk modular dan nilai kuasa elektrik setiap modular adalah 100 kW. Spesifikasi elektrik untuk 100 kW adalah di antara 1.2 kV hingga 1.44 kV untuk voltan dan 0 A hingga 70 A untuk arus. 261 unit 100 kW modular PEMFC dikehendaki untuk mendapatkan kuasa bersih 8,628 kW berdasarkan kecekapan sistem PEMFC 40%.

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LIST OF ABBREVIATIONS

AC	-	Alternate Current
AFC	-	Alkaline Fuel Cell
BELB	-	Bekalan Elektrik Luar Bandar
CAPEX	-	Capital Expenditure
CERs	-	Carbon Emission Credits
DC	-	Direct Current
DMFC	-	Direct Methanol Fuel Cell
ECG	-	East Coast Grid
EFB	-	Empty Fruit Bunch
FiAH	-	Feed in Approval Holder
FiT	-	Feed in Tariff
IPPs	-	Independent Power Producer
KeTTHA	-	Ministry of Energy, Green Technology and Water
MEA	-	Membrane Electrode Assembly
MESTECC	-	Ministry of Energy, Science, Technology, Environment and Climate Change
MFC	-	Molten Carbonate Fuel Cell
MFO	-	Marine Fuel Oil
MOSTI	-	Ministry of Science, Technology and Innovation
NRE	-	Ministry of Natural Resources and Environment
O&M	-	Operation and Maintenance
OPEX	-	Operational Expenditure
OTEC	-	Ocean Thermal Energy Conversion
PAFC	-	Phosphoric Acid Fuel Cell
PEMANDU	-	Pemandu Associates Sdn Bhd
PEMFC	-	Proton Exchange Membrane Fuel Cell
PETRONAS	-	Petroliam Nasional Berhad
PV	-	Photovoltaic
RE	-	Renewable Energy
SAIDI	-	System Average Interruption Duration Index

SEDA	-	Sustainable Energy Development Authority in Malaysia
SESB	-	Sabah Electricity Sdn Bhd
SJAT	-	Stesen Janakuasa Anjung Tanah
SJBA	-	Stesen Janakuasa Baiduri Ayu
SJBS/DK	-	Stesen Janakuasa Bandar Sahabat or Desa Kencana
SJC	-	Stesen Janakuasa Cenderawasih
SJEB	-	Stesen Janakuasa Embara Budi
SJFH	-	Stesen Janakuasa Fajar Harapan
SJGP	-	Stesen Janakuasa Gemala Pura
SJHB	-	Stesen Janakuasa Hamparan Badai
SJJB	-	Stesen Janakuasa Jeragan Bestari
SJKS	-	Stesen Janakuasa Kembara Sakti
SLPM	-	Standard Liter Per Minute
SMR	-	Steam Methane Reforming
SOFC	-	Solid Oxide Fuel Cell
WCG	-	West Coast Grid

LIST OF SYMBOLS

A	-	Ampere
atm	-	Atmosphere
°C	-	Degree Celsius
kg	-	Kilogram
kW	-	Kilowatt
kV	-	Kilo volt
L	-	Liter
MW	-	Megawatt
MWh	-	Megawatt Hour
W	-	Watt

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CHAPTER 1

INTRODUCTION

1.1 Background

Sabah has large rural area and difficult to connect with national grid in terms of physical geography because distance from nearest national grid are more than 20 km. Long transmission lines increase power distribution losses and power transmission losses. According to The Borneo Post on 24th October 2018, Yeo Bee Yin, Minister of Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC), Sabah's electricity problem is not only about generation, interruptions in Sabah are caused by transmission and distribution problems [1]. Hence, standalone power generator is good option to overcome this problem. Installed capacity of power generators in Sabah as of 31st December 2015 are hydro (82.5 MW), natural gas (1231.4 MW), diesel/Marine Fuel Oil (MFO) (897.6 MW), biomass (301.5 MW), photovoltaic (PV) (18.3 MW) and biogas (6.1 MW) [2].

Natural gas power plant is the largest power generator available in Sabah. Instead of hydro, biomass, PV and biogas, OTEC is one of the potential renewable energy available in Sabah. Sabah has potential to develop OTEC in the Sabah Trough up to 50,000 MW [3][4]. Electricity from OTEC can be utilised to produce hydrogen instead of directly delivery the energy to Sabah rural area due to long transmission line. Hydrogen from OTEC is useful for PEMFC to generate electricity. PEMFC can convert chemical energy of hydrogen into electrical energy.

1.2 Problem Statement

Electricity distribution system performance in Sabah is inadequate compare to Peninsular Malaysia and Sarawak. Report entitle “Malaysia Energy Statistic Handbook 2017” published by Energy Commission shows in 2016, unscheduled interruption per 1,000 customers in Sabah is the highest which is 32.15 compare to Peninsular Malaysia and Sarawak which are 6.68 and 6.98, respectively [2]. System Average Interruption Duration Index (SAIDI) for Sabah also is the highest compare to Peninsular Malaysia and Sarawak. Poor electricity distributions interrupt daily activity of people in Sabah. Sabah Electricity Sdn Bhd (SESB) share news from Daily Express on SESB website entitle “Lahad Datu folks want electricity supply reconnected”. The news mention one of the villagers from Batu 1, Jalan Segama Lahad Datu, Sabah urges government to expedite reinstallation of electrical substation for supplying electricity to his village [5]. The villager also said that inoperative electrical substation that being built before should be reactivated to supply electricity to villagers.

According to the villager, they generate their own electricity for their usage because electricity supplied by SESB is not stable. Their monthly expenses increase because they have to buy diesel to operate their own diesel generator. Borneo Today reported the article “Sabah SAIDI 100 lab to find permanent solutions to electricity problem”[6]. This article is about special task force called Sabah SAIDI 100 Lab is launched in Sabah. It is joint programme between Ministry of Energy, Green Technology and Water (KeTTHA) and Pemandu Associates Sdn Bhd (PEMANDU) to improve power distribution quality in Sabah. Dr. Maximus Ongkili, previous Minister of KeTTHA inform that RM3.21 billion are allocated to the SESB since 2001 to enhance the state’s electricity supply infrastructure developments, besides channelled RM7.1 billion to subsidise fuel for power distribution since 2004 to 2017[6].

After the 14th Malaysian general election was held on 9th May 2018, the entire component of Ministry of Science, Technology and Innovation (MOSTI), KeTTHA and related component of Climate Change and Environment from Ministry of Natural Resources and Environment (NRE) had been restructured and formed MESTECC. Federal Government under MESTECC and Sabah Government cooperate to solve the SAIDI problem in Sabah. Efforts from both government show positive result when SAIDI in Sabah reduce from 1856 in 2008 to 241 in 2017 [7][8].

Eventhough SAIDI rate in Sabah reduce, there are 603 villages with 19,761 houses are not receive electricity and 207 houses from 19,761 houses are listed in Rural Electricity Supply Project or Bekalan Elektrik Luar Bandar (BELB) which is under progress [9]. Under BELB, PV hybrid systems are installed to supply electricity in remote area. Installation of PV/diesel mini grid based on guideline 70% PV/battery to 30% diesel or 50% PV/battery to 50% diesel, depending on source available on the site [10].

PV/diesel installation in Sabah is reliable to supply electricity if battery systems have sufficient capacity [11]. If not, fuel consumption for diesel generator increase cause more money to buy diesel [11]. Lead acid battery is the common battery for energy backup in PV power supply system. Typical life time for the battery is 500 to 1200 cycles or numbers of charging and discharging [12]. Others report life time of lead acid battery is 5 to 15 years depend on usage [13]. Short life time of battery is one of the issues that increase cost of operating PV. Instead of battery, PEMFC has potential to combine with PV for energy storage.

From aforementioned statement in background, Sabah has potential to produce hydrogen using OTEC. Felda Sahabat, Sabah is suitable area for pilot project to commercialize hydrogen from OTEC for electricity generation due to easy transportation from OTEC power plant to resident area. Data collection from Felda Engineering Sdn Bhd and through literature search show diesel generator and biomass power plant are existing electricity power plant available in Felda Sahabat [14]. The power plant are equipped with 5 x 1 MW diesel generators as backup throughout breakdowns similarly provide power during boiler inspection in biomass power plant. It’s anticipated that biomass plant use diesel generator for two weeks each year during annual Operation and Maintenance (O&M) of the Empty Fruit Bunch (EFB) facility. PEMFC can replace diesel generator as a backup during O&M as an alternative for clean electricity generation.

PEMFC has flexibility to use as standalone power plant or integrate with other electricity generation such as biomass and PV for energy storage and backup. However, in Malaysia, not much study about cost implementation of PEMFC as off-grid power system to generate electricity. Cost of implementation involves Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). This thesis will discuss of OPEX cost analysis for small scale PEMFC as a baseline for implementation of this system in the future. Main cost for OPEX cost for PEMFC is fuel which is hydrogen to operate the PEMFC. In this thesis, calculation for hydrogen cost based on cost of hydrogen production from OTEC can be guideline for power plant developer in Malaysia to develop power plant using hydrogen supply from OTEC. OTEC is new technology in Malaysia which has potential to produce hydrogen in large scale to meet demand for hydrogen in Malaysia.

1.3 Objectives of Research

The objectives of the research are :

(a) To develop a small scale of off-grid power system using PEMFC as a main power generator for studying the system efficiency.

(b) To calculate OPEX for small scale PEMFC.

(c) To estimate electrical specification for bigger size PEMFC as proposal for Felda Sahabat, Sabah

1.4 Scope

For objective to develop a small scale of off-grid power system using PEMFC as a main power generator for studying the system efficiency, components of small scale of off-grid power system using PEMFC as main power source will be studied based on literature. Components of hydrogen supply and power conditioning which are DC/DC converter and DC/AC inverter that suitable with small scale PEMFC is being search based on literature. Then, all the components will be integrated and analysis of efficiency for 1 kW small scale PEMFC off-grid power system will be evaluated using Alternate Current (AC) load.

To calculate OPEX for small scale PEMFC, measurement of hydrogen consumption not included in the experiment. Hydrogen consumption data for operational cost analysis adopted directly from H-1000XP user manual (data sheet). After that, operational expenditure cost of PEMFC will be calculated based on hydrogen consumption rate and price of hydrogen from OTEC. In addition, data of existing electrical generation type and capacity in case study area which is Felda Sahabat, Sabah will be gathered. From the data, electrical estimation for suitable capacity for PEMFC off-grid system proposal for Felda Sahabat will be estimated.

1.5 Thesis Organization

Chapter 1 of this thesis is mentioned about an overview of the electricity supply in Sabah and about the idea of developing PEMFC off-grid power system using the hydrogen fuel from OTEC. Research objectives and scope to develop a small scale of off-grid power system using PEMFC as a main power generator for studying the system efficiency, calculate operational expenditure cost for small scale and estimate electrical specification for bigger size PEMFC as proposal for Felda Sahabat has been highlighted. After that, in chapter 2, overview about Sabah power generation, PEMFC, and overview of hydrogen are described.

Next, in chapter 3, experimental set up for small scale PEMFC off-grid power system and data collection of existing electrical generation type and capacity in Felda Sahabat, Sabah are described. Efficiency result of small scale PEMFC off-grid power system, operational expenditure cost for small scale PEMFC and estimated electrical specification for bigger size PEMFC are discussed in chapter 4. Finally, chapter 5 presents the conclusion of this work and the recommendation of PEMFC installation in Felda Sahabat, Sabah.

CHAPTER 2

LITERATURE REVIEW

2.1 Sabah Power Generation

Population of Sabah in year 2016 and in year 2017 are 3.80 million and 3.86 million, respectively. However, for year 2018, no actual data is recorded yet. Sabah population increases about 0.06 million from 2016 to 2017 [15]. Population increase in Malaysia will increase energy consumption and economic growth [16]. Thus, SESB should be prepared for increment of energy consumption in Sabah because data shows that population in Sabah is increasing.

Sabah grid system has three voltage level transmission line consists of 275kV, 132 kV and 66 kV that connect all major areas in Sabah and Federal Territory of Labuan. The Sabah grid system is divided into two regions which is West Coast Grid (WCG) and East Coast Grid (ECG) with most of electricity generation and electricity load are in the WCG. ECG and WCG are interconnected through 275 kV Kolopis - Segaliud transmission lines with a distance 246 km [17]. 275 kV Kolopis - Segaliud transmission line is identified as weakest point of interconnection of Sabah Grid System and it is suggested additional interconnection to support existing network for preserving stability of grid [17].

Number of SAIDI in Sabah is the highest compare to Sarawak and Peninsular Malaysia. Figure 2.1 shows the SAIDI of Sabah, Sarawak and Peninsular Malaysia. SAIDI is one of the performance indicator used by electricity provider to monitor performance of distribution system. SAIDI is the average electricity interruption in minutes experienced by customers in a year. High SAIDI indicate bad performance of distribution system.

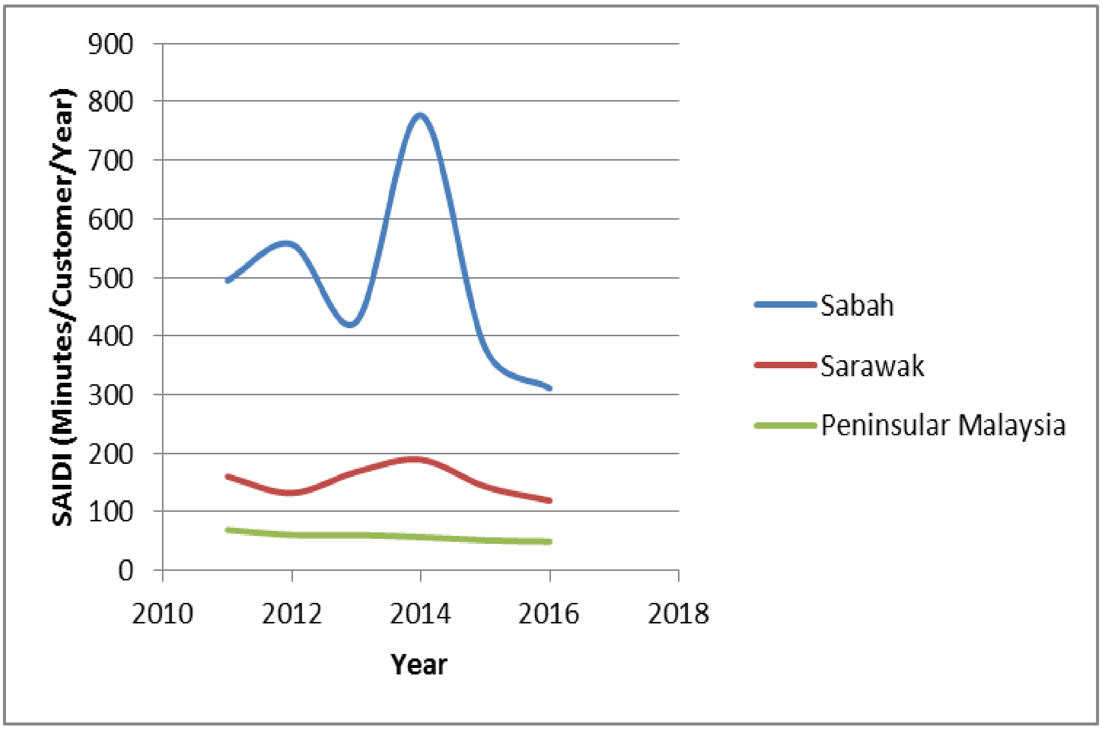


Figure 2.1 SAIDI of Sabah, Sarawak and Peninsular Malaysia

Based on finding in [17] and high SAIDI for Sabah distribution system, it is good for SESB to consider having two totally separate grid system and develop more power generation at east coast to increase stability of ECG. SESB should utilize potential of Renewable Energy (RE) in east coast area to increase power generation capacity in east coast and avoid long interconnected transmission line that risky the stability of grid. RE available in east coast area are PV, biogas, biomass, small hydro and OTEC. For remote area, off grid power supply from RE is suitable for electricity generation and distribution system. Off-grid power system is suitable for remote area in order to reduce cost of connection link to the nearest grid power station.

There are many types of power generator for off-grid power system which are wind power, PV, diesel generators, biogas generator and fuel cells. The system are either alone or hybrid power system. Hybrid system consists of wind power plant and PV power plants are most suitable for the off-grid system supply [18]. The claim is not 100% true because it is depends on the availability of the source. Advantages of wind power plant and PV are needed no fuel to operate and there are the possibility of minimizing the capacity for each power sources. In addition, when one source output decrease, another source can supplied electricity to maintain total output for the system. However, control system for hybrid system is more complicated than single source power system. For Malaysia, wind power plant is limited to certain location and should utilize PV to generate electricity because Malaysia has high irradiance rate receive all over the year at most of the location.

Social acceptability of RE in Malaysia has been conducted by [19]. Regarding measuring the level of interest in renewable energy, the result shows majority of Malaysian believes that PV is the most suitable RE in Malaysia [19]. However, PV has weakness which is cannot produce electricity 24 hour. At night PV cannot produce electricity and during cloudy day performance of PV will drop. PV should be installed with energy storage system. Lead acid battery is common being used to store excess electricity produce by PV. Instead of lead acid battery, PEMFC also can be attached to the system as backup.

SESB is the largest electricity producer in Sabah. However, over the years, Independent Power Producer (IPPs) generates their own electricity instead of relying only on SESB [20]. Report from Energy Commission shows instead of SESB and IPPs, power producer types in Sabah are co-generation, self-generation and Feed in Tariff (FiT) [2]. IPPs are the largest power producer type in Sabah which is about 47.39% of total electricity generation in Sabah. IPPs generate electricity and distribute electricity using Sabah Grid owned by SESB. SESB pay to them for the electricity. IPPs available in Sabah are Ranhill Powertron Sdn Bhd, Sepangar Bay Corporation Sdn Bhd, Ranhil Powertron II Sdn Bhd, Kimanis Power Sdn Bhd, SPR Energy (M) Sdn Bhd, Stratavest Sdn Bhd and Serudong Power Sdn Bhd.

Co-generation refers to power producer whom utilize the electricity and the heat from a single power plant. Example of co-generation producer in Sabah is Felda Palm Industries Sdn Bhd. Felda Palm Industries Sdn Bhd generates electricity from biomass using steam turbines power plant. Steam turbines power plant not only generated electricity but it also produced heat for drying the palm oil in crude palm oil milling process. Self-generation in Sabah refers to producer whom produces electricity for their own usage and capacity is below 5 MW.

Malaysia Government introduces FiT to promote growth of RE sector in Malaysia. Sustainable Energy Development Authority in Malaysia (SEDA) is the institution that responsible to monitor the FiT mechanism. Sabah FiT mechanism is SESB buy electricity from producers whom generate electricity from renewable energy and set the rate of price. SESB pay for RE supplied to the electricity grid for specific duration based on RE source. The duration for biomass and biogas source are 16 years while for small hydro power and PV are 21 years. Installed capacity of power generation by each power producers in Sabah as of 31st December 2015 is tabulated in Table 2.1.

Table 2.1 Installed capacity of power generation in Sabah as of 31st December 2015 [2]

Producer	**Source**						
	Hydro (MW)	**Natural Gas (MW)**	**Diesel/MFO (MW)**	**Biomass (MW)**	**Solar (MW)**	**Biogass (MW)**	**Total**
SESB	76.0	112.0	180.9	-	-	-	368.9
IPPs	-	1012.6	189.9	-	-	-	1202.5
Co-generation	-	106.8	-	122.7	-	-	229.5
Self generation	-	-	526.8	135.8	0.1	3.4	666.1
FiT	6.5	-	-	43.0	18.1	2.7	70.3
Total	82.5	1231.4	897.6	301.5	18.2	6.1	2537.3

2.1.1 Photovoltaic in Sabah

Solar energy in Malaysia first introduced as one of the five fuels in electricity generation through the Fifth Fuel Policy in 2001 [21]. Existing PV installation in Malaysia whom registered with SEDA can be monitored online at website [22]. First time user must sign up and can log in after sign up process finish. Required information to sign up is personal email and set own password. Email verification will be sent to registered email and after email verification process, sign up process finish. From the website, user can see the list of available PV power plant. Appendix A shows the screenshot list of existing PV power plant from website [22]. User can sort based on location, capacity, plant type and plant number. From the website, installed numbers of PV in Sabah as of 3rd December 2018 are six plants.

Field study about the existing solar PV-diesel hybrid in 11 schools in Sabah is conducted by [11]. Schools name and district are Sekolah Kebangsaan Luasong (Tawau), Sekolah Kebangsaan Labuk Subur (Sandakan), Sekolah Kebangsaan Litang (Kinabatangan), Sekolah Kebangsaan Golong (Beluran), Sekolah Lung Manis (Sandakan), Sekolah Kebangsaan Matupang (Ranau), Sekolah Kebangsaan Poring (Tuaran), Sekolah Kebangsaan Tanjung Paras (Lahad Datu), Sekolah Menengah Kebangsaan Timbua (Ranau), Sekolah Kebangsaan Sungai Sungai (Beluran) and Sekolah Kebangsaan Rungus Nahaba (Ranau). All installed PV-diesel hybrid are reliable except for Sekolah Kebangsaan Poring [11]. Due to location of Sekolah Poring is at highland (836 m from sea level), this area is always surrounded with cloud especially in the afternoon [11]. As a result, there is low radiation level in Sekolah Kebangsaan Poring and highest charge factor find at Sekolah Kebangsaan Poring which is 1.58 compare to other schools which are 1.34 in average [11]. Normal charge factor for battery is 1.2 [23]. Higher charge factor means more energy being used to charge batteries compare to power that it can be delivered. Hence, this condition reduces the reliability of the PV system.

Lead acid batteries are commonly used in PV system due to excellent electrical performance and relatively low cost [24]. However, life cycle of lead acid battery is short which is only between 500 to 1200 charge/discharge cycles [12]. Actively controlled battery – supercapacitor hybrid energy storage systems has great ability in generating smoother battery current and reducing peak current which are good for battery longevity [24]. Supercapacitor manages to overcome the problem when high demand peak current and surge current occurred [25]. The system reduces current stress in batteries, improve lifecycle of battery and reduce operating and maintenance cost for battery in PV system [25].

Instead of using ultracapacitor and lead acid battery for energy storage in PV system, electrolyzer and PEMFC can be integrated with PV to store energy. Excess energy from PV is used for producing hydrogen by electrolyzer and being used by PEMFC to produce electricity when PV is not generating electricity at night or cloudy day. Figure 2.2 shows the PV – PEMFC hybrid system. The system shows power supply system for the Direct Current (DC) load. In the system, electricity from PV regulate by DC/DC converter based on DC load input voltage. At the same time, excess electricity from PV supply to the electrolyzer for electrolysis process. Electrolyzer is an electrochemical device that used electricity to break water into hydrogen and oxygen. Hydrogen produce by electrolyzer being stored in hydrogen tank, later will be used by PEMFC to generate electricity when PV cannot generate electricity during night or cloudy day.

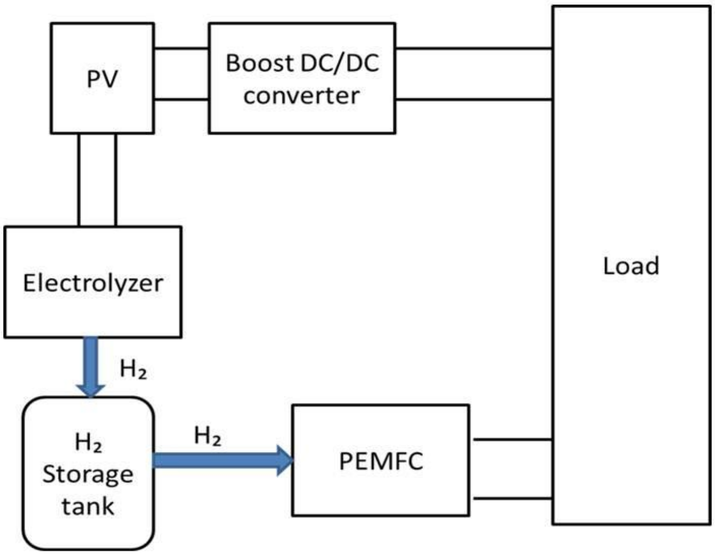


Figure 2.2 Hybrid PV-PEMFC system diagram [26]

2.1.2 Biogas and Biomass in Sabah

Installed capacity as 31st December 2015 of biogas and biomass in Sabah are 6.1 MW and 301.5 MW, respectively [2]. Potential of electric power (MWh) which can be produced by palm oil in Sabah is 2,382 MWh [27]. Table 2.2 and Table 2.3 show list of Feed in Approval Holder (FiAH) biogas and biomass power plant in Sabah based on data from SEDA website respectively [28]. Sahabat biomass power plant not included in the list because not listed in FiT programme.

Table 2.2 List FiAH biogas power plant in Sabah [28]

Plant Owner	**Location**	**Capacity (MW)**
TSH Bio Gas Sdn Bhd	Tawau	3.1950
QL Tawau Biogas Sdn Bhd	Tawau	2.4000
Mistral Engineering Sdn Bhd	Sandakan	4.0000
Prosperous Sebatik Sdn Bhd	Tawau	3.0000
Atlantica Sdn Bhd	Sandakan	3.0000
Konsep Muktamad Sdn Bhd	Tawau	1.0000
Cahaya Bumijasa Sdn Bhd	Tawau	3.8000
Desa Kim Loong Palm Oil Sdn Bhd	Keningau	2.4000

Table 2.3 List FiAH biomass power plant in Sabah [28]

Plant Owner	**Location**	**Capacity (MW)**
Kina Biopower Sdn Bhd	Sandakan	11.5000
Seguntor Bioenergy Sdn Bhd	Sandakan	13.4000
TSH Bio-Energy Sdn Bhd	Tawau	12.0000
Cash Horse (M) Sdn Bhd	Sandakan	12.0000
IOI Bio-Energy Sdn Bhd	Sandakan	15.0000

2.1.3 Small Hydro in Sabah

Table 2.4 shows list FiAH hydro power plant in Sabah based on data from SEDA website [28]. Most of the power plants are in Kota Marudu, Sabah.

Table 2.4 List FiAH hydro power plant in Sabah [28]

Plant Owner	**Location**	**Capacity (MW)**
Esajadipower Sdn Bhd	Kota Belud	2.0000
Esajadipower Sdn Bhd	Kota Marudu	4.5000
One River Power Sdn Bhd	Kota Marudu	13.5000
One River Power Sdn Bhd	Kota Marudu	5.6000
One River Power Sdn Bhd	Kota Marudu	10.0000
Telekosang Hydro Two Sdn Bhd	Tenom	16.0000
Telekosang Hydro One Sdn Bhd	Tenom	24.0000

2.1.4 Geothermal in Sabah

Malay Mail published article on 5th August 2016 regarding geothermal power plant in Sabah [29]. Article entitle “Minister:Malaysia’s First Geothermal Plant to be operational by 2018” mentioned that according to former Minister of KeTTHA, Datuk Seri Dr. Maximus Ongkili announced geothermal power plant which located in Apas Kiri in the Sabah east coast district, is set to export 30 MW power to SESB [29]. Estimated cost for this project is RM600 million total investment with an initial grant of RM35 million from the federal government [29]. Tawau Geothermal Project is the first geothermal power plant in Malaysia and it is Independent Power Plant under Tawau Green Energy [30]. This geothermal source was first discovered in Apas Kiri, Tawau during 2008 to 2009 by Malaysia’s Minerals and Geoscience Department [30]. Unfortunately, on 6th December 2018, Malay Mail reported Sabah geothermal power plant project found abandoned [31]. MESTECC Minister Yeo Bee Yin said based on her visit to the site, there was no development activities on site [31]. The project which being developed by Tawau Green Energy Sdn Bhd being stopped and actually on 29th August 2018, SEDA has decided to cancel FiT approval for this project [31].

2.1.5 Ocean Thermal Energy Conversion in Sabah

Marine survey in the South China Sea in 2006 to 2008 by Malaysia National Minister's Department with the technical support of Petroliam Nasional Berhad (PETRONAS), Department of Survey and National Mapping, the Hydrography Directorate of Royal Malaysian Navy and Department of Geosciences Malaysia found the temperature differences between deep sea water and surface water of Sabah Trough is more than 20°C which has potential for OTEC [32]. OTEC power plant is able to produce electricity through the temperature differential between cold deep ocean water and warm surface ocean water to run turbine and produce electricity. South East Asia includes Malaysia has great potential for OTEC. As of 2018, no OTEC has been developed in Sabah.

In 2003, Lockheed Martin and Reignwood Group which are one of the companies who actively involved in OTEC technology announce that 10 MW OTEC power plant will be built in China [33]. This project is in on going and China reported until December 2017, Institute of Oceanography of State Oceanic Administration has been developing a 10 kW OTEC prototype and now is undergoing experimental test [34]. Japan are successfully developed OTEC and the plant is located in Kume Islands with capacity 50 kW. Instead of generating electricity, OTEC also have another advantages. Deep ocean water has many advantages like for aquaculture and air conditioning, mineral extraction and water desalination [35][36]. For an example, Hareruma Island, Japan uses deep ocean water for aquaculture of abalone and low temperature mango plantation.

Another advantage and disadvantage of OTEC in term of power and technical are OTEC plant can supply steady power and not affected by weather and seasons change and OTEC use common thermodynamics devices and equipment such as turbine and heat exchanger. Disadvantages of OTEC are it has low efficiency, plant has to withstand severe ocean conditions and equipment has to resist the corrosive effect of sea water [37].

High cost required to set up power grid to distribute electricity from OTEC power plant to household because of OTEC location far from land area. Besides generating electricity, OTEC has a big potential for seawater electrolysis and hydrogen production. Hydrogen nowadays becomes one of important energy carrier due to development of fuel cell technology. Fuel cell mainly uses in vehicles. It also can be used as household power supply [38][39]. Fuel cell for household generates electricity by utilizing mass production of hydrogen from OTEC power plant. Figure 2.3 shows OTEC power plant concept.

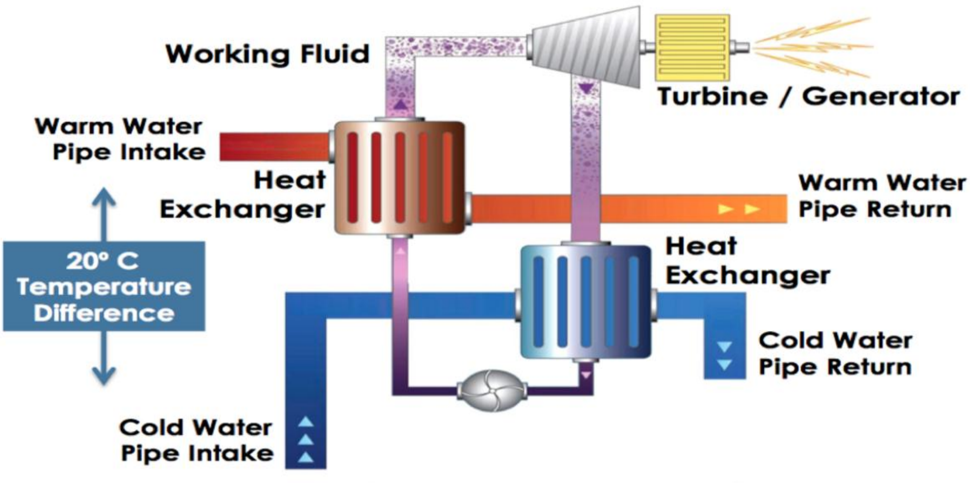


Figure 2.3 OTEC power plant concept taken from [40]

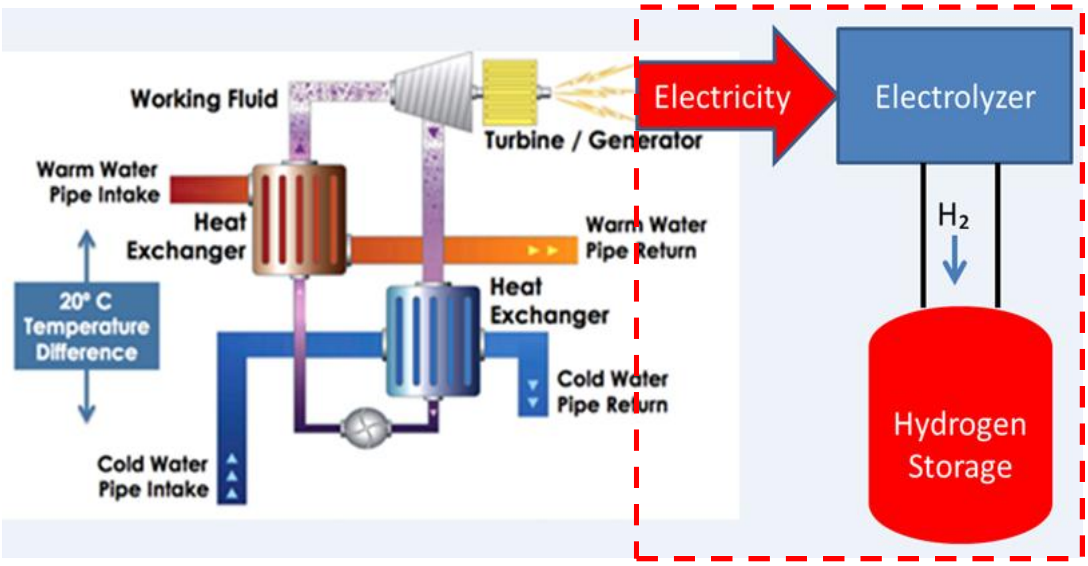


Figure 2.4 OTECpower plant concept with electrolyzer and hydrogen storage [40]

Figure 2.4 shows OTEC power plant concept with electrolyzer and hydrogen. Jacques Arsene D'Arsonval is the person who proposed this system in 1800's and after 130 years later the first prototype was built by George Claude [41]. In OTEC system, there are piping system for cold and warm water, heat exchanger, working fluid and turbine. To make sure that this system can run, temperature difference between surface water and deep water must be more than 20°C [42][43]. Ammonia is common fluid used in OTEC system because it has low boiling point. Warm surface water will heat ammonia and ammonia will drive the turbine to generate electricity. Heated ammonia flow through the heat exchanger and being cold by cold deep sea water that is being pumped up from bottom. Cold ammonia flows through another heat exchanger and being heated by heat exchanger. Again heated ammonia will drive the turbine and this cycle continues to produce electricity.

Electricity from OTEC is not suitable to supply directly to the residential area because it is far from land. Hence, electricity can be used to generate hydrogen through electrolysis process. Electricity from OTEC supply to electrolyzer, then electrolyzer will separate water into hydrogen and oxygen. After that, hydrogen can be stored in hydrogen tank and transported to the land for PEMFC usage. Estimation for electrolyzer with efficiency 100%, 8.9 L water and 39 kWh of electricity are needed to produce 1 kg of hydrogen. Commercialize electrolyzer with efficiency

56% to 73% requires 70.1 kWh to 53.4 kWh of electricity to produce 1 kg of hydrogen at 25 °C and 1 atm [44]. Thermal efficiency of OTEC is around 5% to 6 % [45].

2.2 Proton Exchange Membrane Fuel Cell (PEMFC)

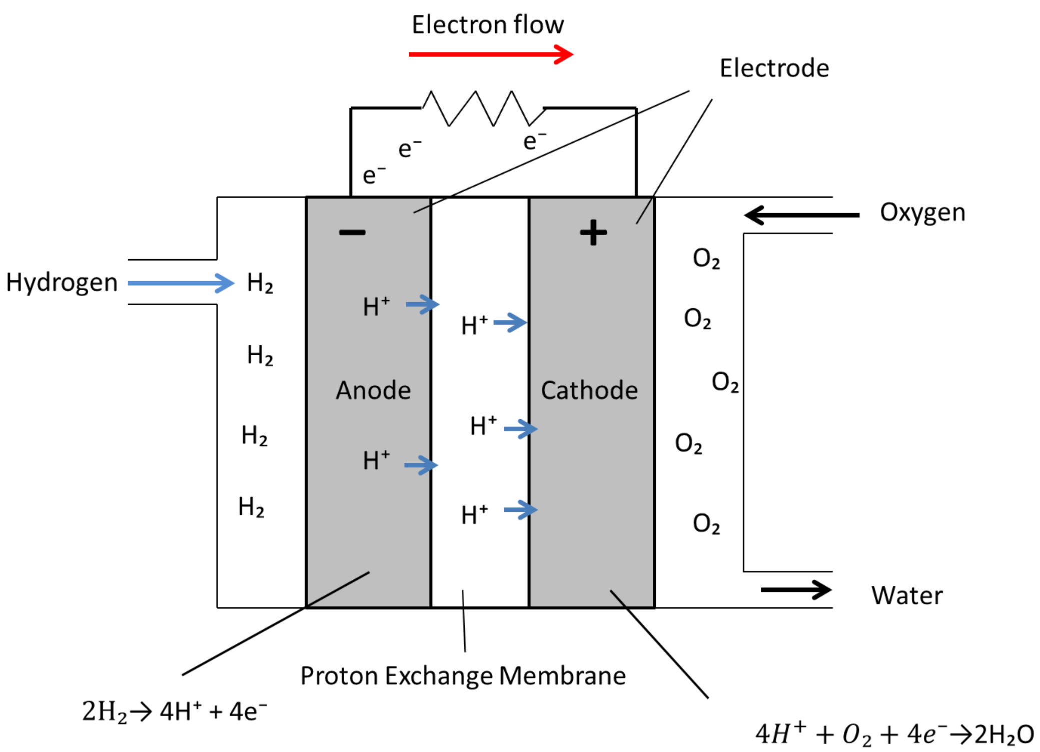


Figure 2.5 PEMFC concept [46]

Figure 2.5 shows the PEMFC concept. PEMFC generates electricity through the chemical reaction in the cell. PEMFC consists of two electrodes which are anode and cathode. At the anode, hydrogen loss electron and become hydrogen ions. Hydrogen ions spread throughout membrane to the cathode. Electrons from hydrogen flow to the cathode using external circuit because proton exchange membrane only allow proton to go through it. At the cathode, hydrogen ions receive electron and react with oxygen. Waste product of this chemical reaction is only water. The overall chemical reaction is shown in Equation (2.1).

$$H^2(g) + \frac{1}{2}O^2(g) \rightarrow H^2O(g) \tag{2.1}$$

Research has been conducted in various methods to improve efficiency of fuel cell. Some of the researchers focus on improvement of Membrane Electrode Assembly (MEA) which is main part of PEMFC [47]. MEA is very important for PEMFC because chemical reaction to produce electricity happen at MEA. Figure 2.6 shows MEA components which are consist of membrane, catalyst layer and gas diffusion layer. Membrane allow positive ion to go through but block electron. Catalyst layer have anode and cathode side. On the anode side, hydrogen split into hydrogen ion and electron. On the cathode side, oxygen from air reacts with hydrogen ion and producing water. Gas diffusion layer transport hydrogen fuel to the catalyst layer for chemical reaction and produce electricity. At the same time, gas diffusion layer also remove water to avoid membrane damage. Sealing material is to seal MEA components together.

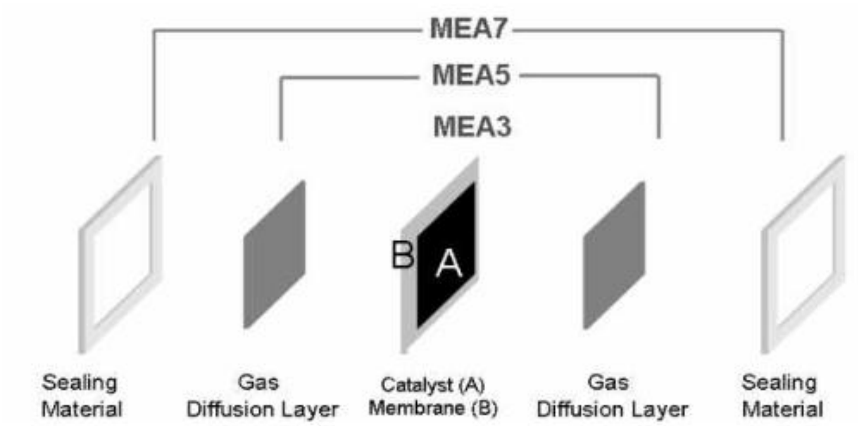


Figure 2.6 Membrane Electrode Assembly (MEA) [48]

PEMFC can be used for transportation and also domestic power supply. Nowadays, car's manufacturer companies such as Honda, Toyota and Hyundai introduce their fuel cell vehicle. For domestic power supply, Japan through the Ene - Farm Scheme installed the fuel cell at over 120,000 residential. This project shows that by using fuel cell CO_2 emission can be reduced about 38% in one year [49]. Installed units of fuel cell increase from 2,550 in year 2009 to

154, 045 in year 2015 [50]. This remarks fuel cell market demanding is increasing. For domestic power supply, fuel cell is being used either alone or combined with other type of renewable energy such as solar energy. Fuel cell is best option to overcome one of the problem that encounter with solar energy which is no electricity generate at night. With fuel cell, energy from solar system can be used to break water into oxygen and hydrogen using electrolyzer and stored for PEMFC usage a night. With this integration, the system is able to generate electricity for 24 hour. In this study, standalone off-grid power system using PEMFC as power generator is being proposed for studying the efficiency of the system and operational cost.

Basically, fuel cell off-grid system consists of hydrogen supply unit, PEMFC as power generator and power conditioning unit which is DC/DC converter and DC/AC inverter. Fuel cell has many types and classified by electrolyte type being used. Examples of fuel cell are Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MFC), Solid Oxide Fuel Cell (SOFC), Proton Exchange Membrane Fuel Cell (PEMFC) and Direct Methanol Fuel Cell (DMFC). For fuel cell off-grid system, PEMFC is being used as power generator because it has low operating temperature and easy to run.[51][52]. Table 2.5 shows comparison of different type of fuel cells [53].

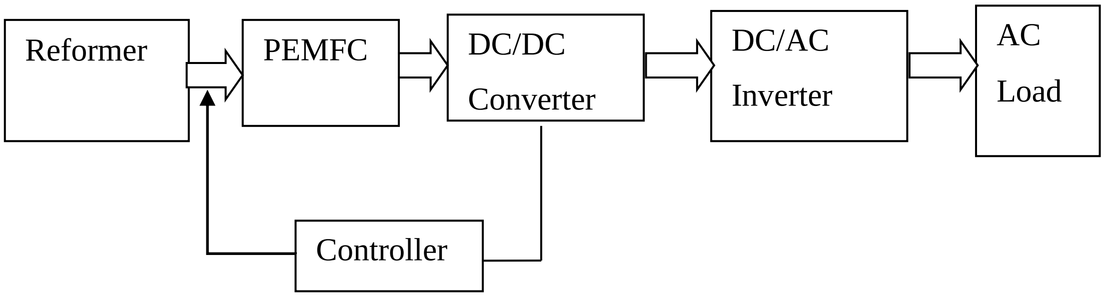
Table 2.5 Fuel cell types [53]

Fuel Cell	**Temperature (°C)**	**Application**	**Advantages**	**Disadvantages**
Alkaline Fuel Cell (AFC)	50-90	Space application	High efficiency	Intolerent to CO_2 in impure H_2 and air, corrosion , expensive
Phosphoric Acid Fuel Cell (PAFC)	175-220	Stand-alone & combined heat & power	Tolerant to impure H_2, commercial value	Low power density, corrosion & sulfur poisoning
Molten Carbonate Fuel Cell (MFC)	600-650	Central, stand-alone & combined heat & power	High efficiency , commercial value	Electrolyte instability, corrosion & sulfur poisoning
Solid Oxide Fuel Cell (SOFC)	800-1000	Central, stand-alone & combined heat & power	High efficiency & direct fossil fuel	High temperature, thermal stress failure, coking & sulfur poisoning
Polymer Electrolyte Membrane Fuel Cell (PEMFC)	50-100	Vehicle & portable	High power density, low temperature	Intolerent to CO in impure H_2, expensive
Direct Methanol Fuel Cell (DMFC)	50-120	Vehicle & small portable	No reforming, high power density & low temperature	Low efficiency, methanol crossover & poisonous by product

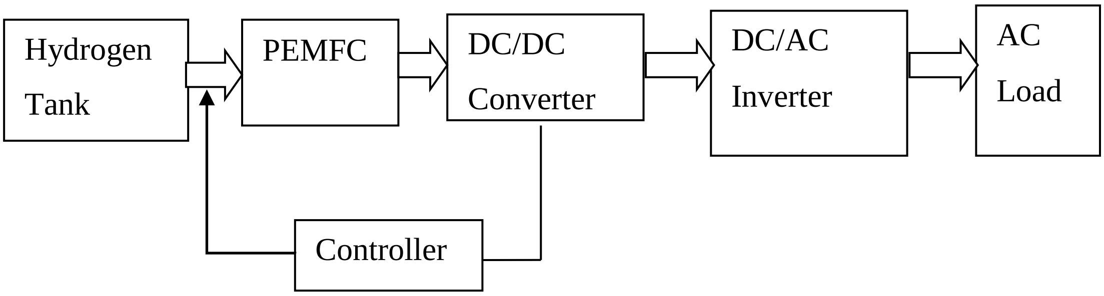
In off-grid system, the power conditioning unit which is included DC/DC converter and DC/AC inverter are necessary [54]. Off-grid power system using PEMFC can be developed by including reformer to the system or directly feeding pure hydrogen to PEMFC [55]. Reformer is for generating hydrogen through the reforming methane. Figure 2.7 shows the small scale off-grid power system using PEMFC as power generator with reformer and without reformer. The system with reformer required more time for startup because reformer have to convert methanol to hydrogen first before supply to the PEMFC. Hence, in this research, the system without reformer is used because for future planning, hydrogen from OTEC comes in pure hydrogen and need no reformer in the system.

The system consists of PEMFC, DC/DC converter, DC/AC inverter, controller, AC load and 99.99% pure hydrogen that will supplied to the system as fuel. Hydrogen from hydrogen tank flow into PEMFC, then this hydrogen will be converted from chemical energy to the electrical energy through chemical reaction in PEMFC. PEMFC output voltage will regulate using DC/DC converter to the required value based on system design. In this research, PEMFC stack has built in DC/DC converter which is step down the stack voltage to 12 V for the fuel cell controller and other peripheral parts (hydrogen sensor, blower and temperature sensor) to operate.

For experimental setup, two DC/DC converters are used which are one is built in DC/DC converter and another one external DC/DC converter use for regulating input voltage for inverter. Detail connection will be explained in chapter 3. Stack is referring to PEMFC because single cells are stacked together in PEMFC. Functions of controller in this system are controlling stack temperature (below 65 °C), control stack purge rate, monitoring stack current and voltage, monitoring H_2 concentration, protecting stack from possible failures (stack low voltage (25 V), over current (50 A), over temperature protection (68 °C), control hydrogen supply and shut off, and communication with computer for data logging. DC/AC inverter is necessary in this system in order to invert DC output voltage from PEMFC to the AC voltage before supplied to the AC load.



(a)



(b)

Figure 2.7 Small scale off-grid power system using PEMFC as power generator; (a) with reformer (b) without reformer

To get big scale PEMFC off-grid power system, small unit of PEMFC can be stacked together. The Dutch fuel cell manufacturer (Nedstack), run a project of Solvay 1 MW PEMFC Project. In this project, 168 units of 10 kW PEMFC are stacked up together to get peak power 1.7 MW PEMFC. However, output power is 1 MW with 60% efficiency [56]. This project has been installed in Solvay chlorine plant in Lillo, Belgium. Nedstack is working on the project called DEMCOPEM-2 MW to build 2 MW PEMFC in Yingkaou, China and target to be completed by the end of 2018 [57]. This project is completed and installed on site at Ynnovate Sanzheng (Yingkou) [58]. Figure 2.8 shows the DEMCOPEM-2 PEMFC Power Plant at Ynnovate, Yingkou.

Figure 2.8 DEMCOPEM-2 PEMFC power plant at Ynnovate, Yingkou [58]

2.3 Overview of Hydrogen

Hydrogen is energy carrier that can be converted to produce electricity. Steam Methane Reforming (SMR) and water electrolysis are methods to produce hydrogen. Equation (2.2) and Equation (2.3) show chemical reaction of extracting hydrogen from natural gas (methane). SMR consists of two steps, first step is methane reforming takes place in the present of catalyst at temperature (500°C to 900°C) and pressure 30 atm. Second, CO then reacts with steam to produce H_2 and CO_2. Figure 2.9 shows the steam reformer which is steam from the heater is mix with flammable gas, which contains methane to begin the response. The steam-gas mixture enters the reformer from the inlet manifold. The transforming tubes are encompassed by burners, keeping at high temperature. At high temperatures, methane (CH_4) responds with steam (H_2O) to deliver hydrogen (H_2) and carbon monoxide (CO). The present of a nickel catalyst enables this procedure to respond all the more rapidly and to hold more hydrogen gas. The hydrogen-carbon monoxide mixture leaves the reformer via cold outlet manifold system. Carbon monoxide is definitely not a helpful result of the response and might be unsafe whenever discharged into the earth [59].

$$CH_4(g) + H_2O(g) \rightarrow 3H_2(g) \ + CO(g) \tag{2.2}$$

$$CO(g)+H_2O(g)\rightarrow H_2(g)+CO_2(g) \tag{2.3}$$

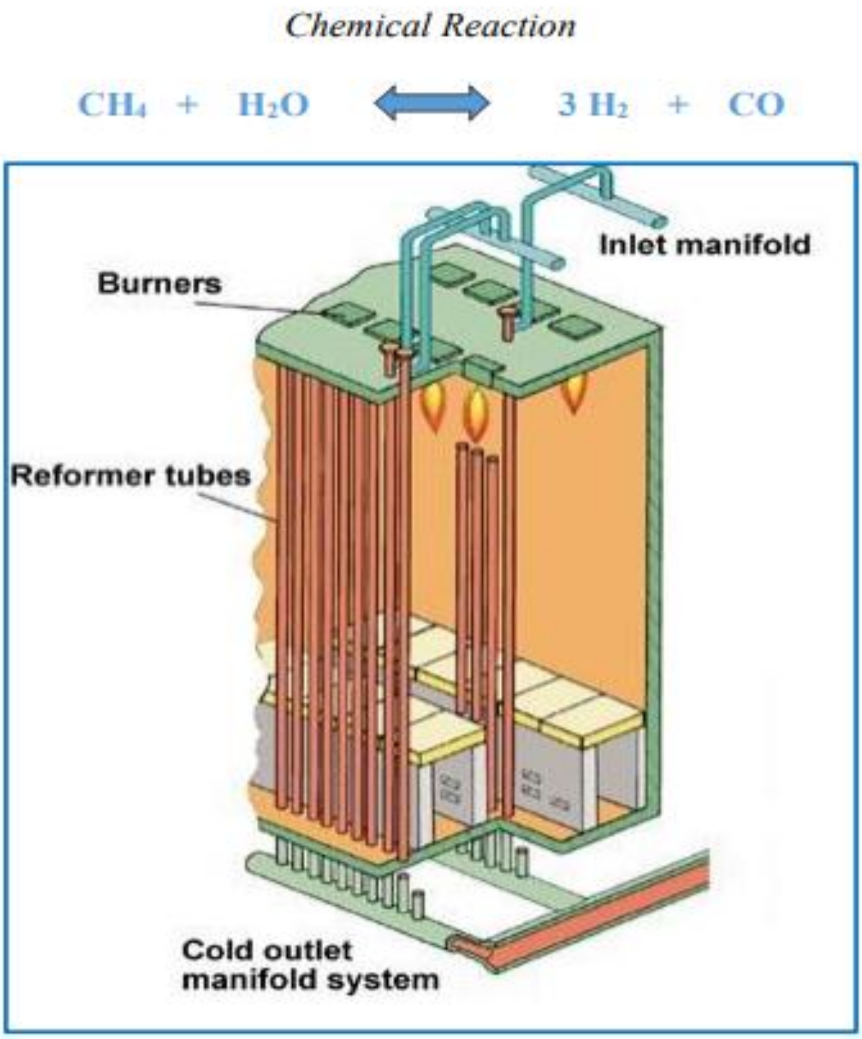


Figure 2.9 Steam reformer [59]

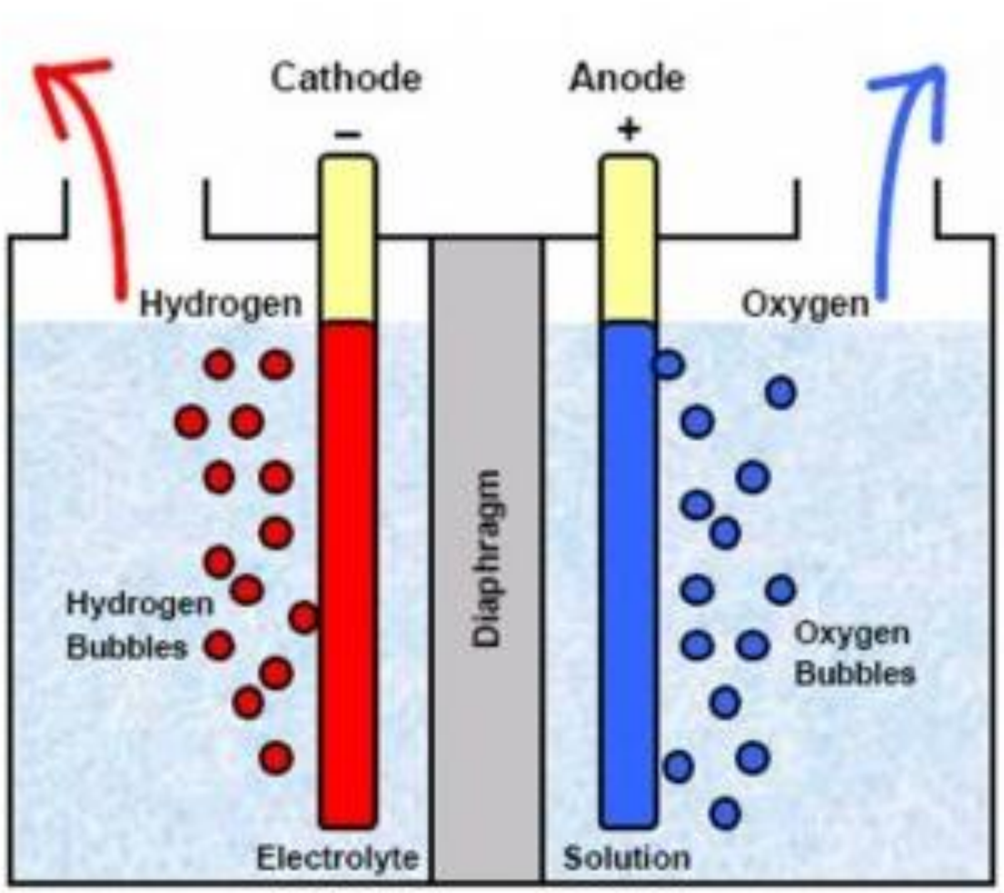


Figure 2.10 Standard electrolysis [60]

Equation (2.4) shows chemical reaction of extracting hydrogen from water which is water separated into hydrogen and oxygen using electrolysis process. Electrolyzer is electrochemical device that utilize an electric current to separate a water particle (H_2O) into hydrogen (H_2) and oxygen (O_2). At the cathode, reduction reaction occur which is electron from cathode is given to hydrogen cations to form hydrogen gas. At the anode, oxidation reaction occur which is oxygen lost electron to form oxygen gas. Hydrogen can be produced via electrolysis of water from any electrical source, including utility grid power, PV, wind power, hydropower, nuclear power or OTEC. Electrolyzer has a positive and negative side, similar to a battery. Hydrogen gas is created on the negative side while oxygen gas is produced on the positive side as shown in Figure 2.10. If attach empty tubes or cylinders to either side, gases can be collected.

$$H_2O(l) \rightarrow H_2(g) + O_2(g) \tag{2.4}$$

One of the reason hydrogen became popular as future energy is because of its cleanliness. Cleanliness of power system using hydrogen fuel depends on hydrogen production method. Producing hydrogen from OTEC water electrolysis can keep cleanliness of power system using hydrogen fuel. Table 2.6 shows cost of hydrogen based on OTEC size. The bigger the size of OTEC plant, the less the cost of hydrogen production [44].

Table 2.6 Cost of hydrogen based on OTEC size [44]

Nominal Plant Size OTEC (MW)	**Cost of Hydrogen in $/kg**
10.00	14.48
35.00	7.22
50.00	6.66
53.50	5.07
100.00	4.75

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Experiment Set up for Small Scale Off-grid Power System

Figure 3.1 shows experimental set up for 1 kW PEMFC off-grid power system. The system consists of hydrogen gas supply, PEMFC set, DC/DC converter, DC/AC inverter, 1 kW load and monitor for performance monitoring. PEMFC H-1000XP model from Horizon Fuel Cell Company with power rated 1 kW is being used. Table 3.1 shows specification of PEMFC (follow details in Appendices C). Based on specification, H-1000XP can deliver up to 33 A of current. The operating voltage ranges from 46 V (no load) to 30 V (full load). Recommended operating point by manufacturer is at 33 A @ 30 V. Hydrogen pressure for operating PEMFC is 0.5 bars. It is very important to set at 0.5 bars to avoid membrane from damage. The battery attach to the system for startup.

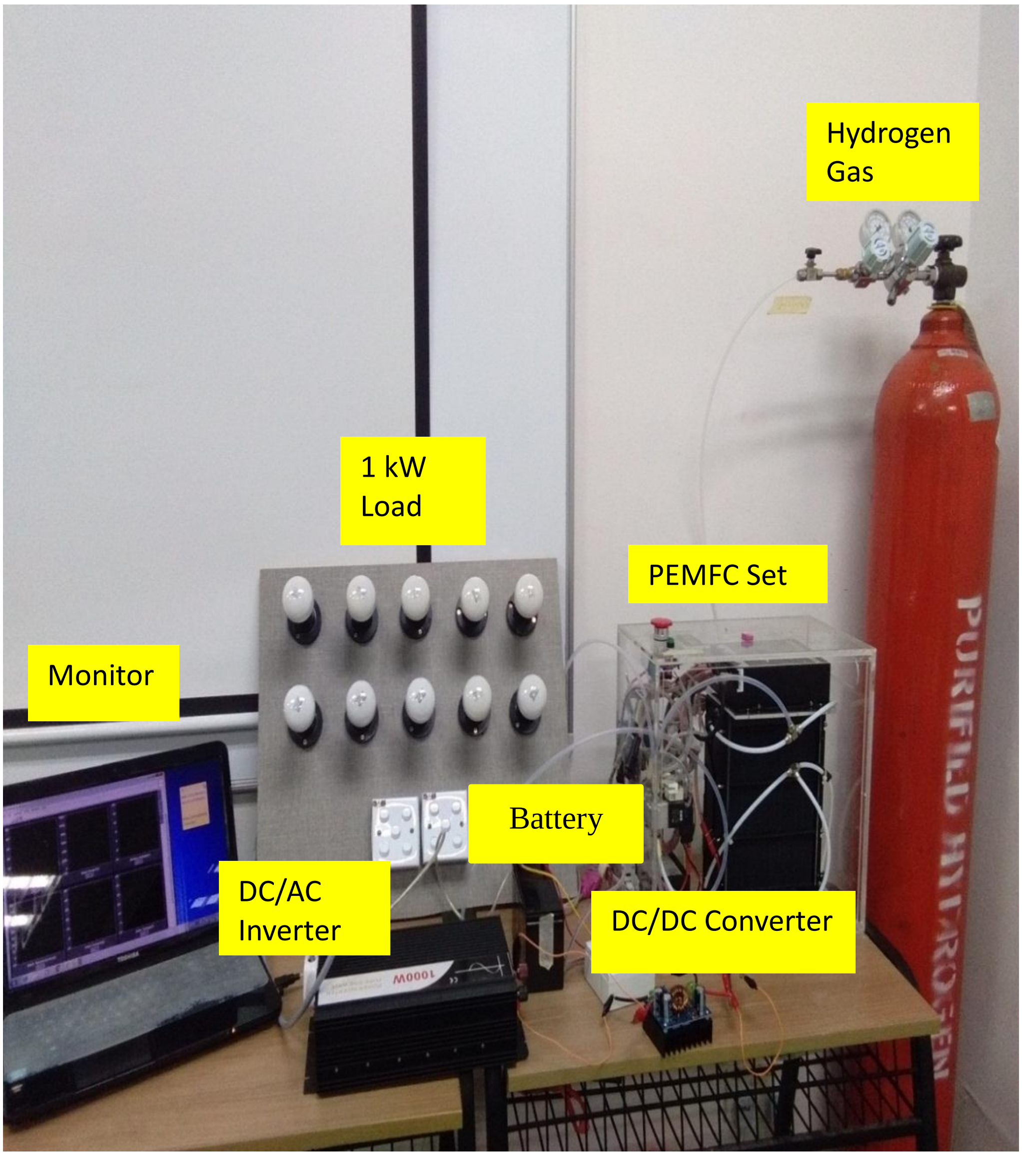


Figure 3.1 Experimental set up for PEMFC off-grid power system

Table 3.1 Specification of 1 kW PEMFC [61]

	Category	**Value**
	Type of fuel cell	PEM
Physical	Number of cells	50
	Dimensions	264mm x 203mm x 104mm
	Weight	11.7kg
Performance	Peak Power	1000W
	Rated current	0 - 33.5A @30V
	DC Voltage	25V - 48V
Fuel	Reactants	Hydrogen and air
	Composition	99.99% dry H_2
	H_2 pressure	0.50 - 0.65 bar
	Hydrogen Consumption @1000W or flowrate	12.5 SLPM (standard liter per minute)
Operation	External Temperature	5-35°C
	Max stack temperature	65°C
	Humidification	Self-humidified
	Cooling	Air
	Start up battery	12 V
Monitoring	RS232	System Status/Historical data

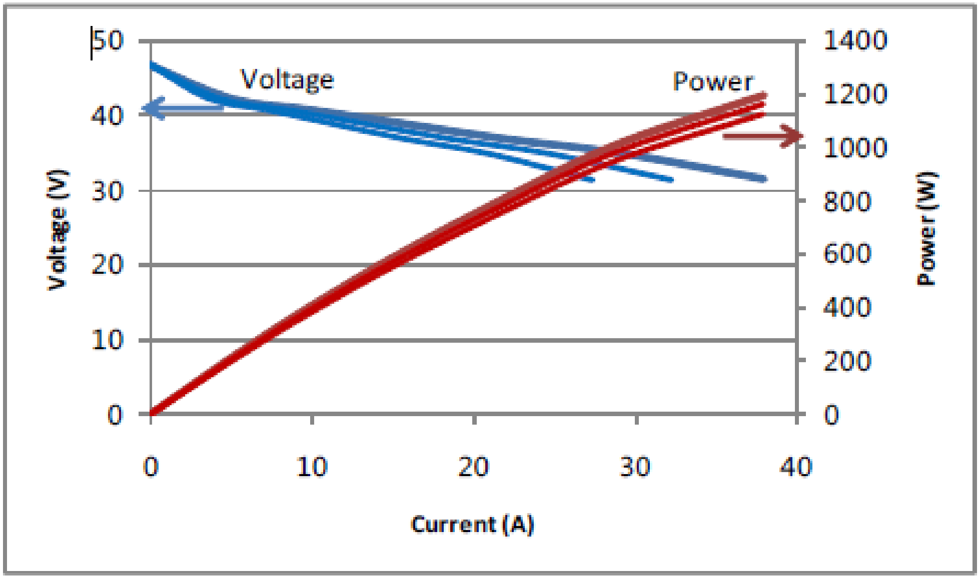


Figure 3.2 Polarization curve for H-1000XP [61]

Figure 3.2 shows polarization curve for H-1000XP from user manual provided by manufacturer. Graph shows at no load, PEMFC output voltage is 48 V. When current increase, PEMFC output voltage will drop. For 1 kW output power, voltage is 36 V and current is 30 A.

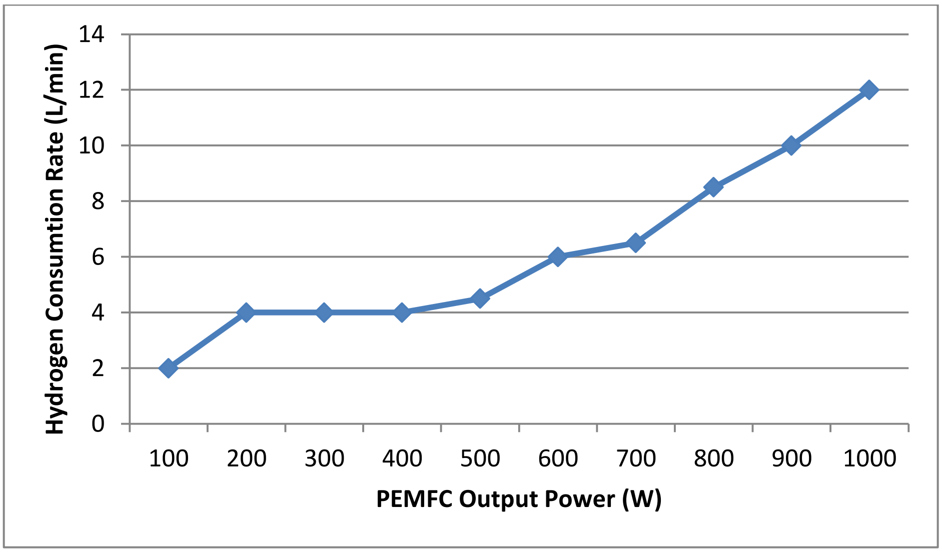


Figure 3.3 Hydrogen consumption rate at different output power [61]

Figure 3.4 Alternate Current (AC) load

Figure 3.3 shows the hydrogen consumption rate at different output power based on H-1000XP user manual. More hydrogen consumes by PEMFC to deliver more power. Figure 3.4 shows AC load which indicate power of each bulb is 100 W. To test amount of power that PEMFC can deliver to the load, switch is on one by one. One switch controls one bulb and load power has been tested with increment step of 100 W.

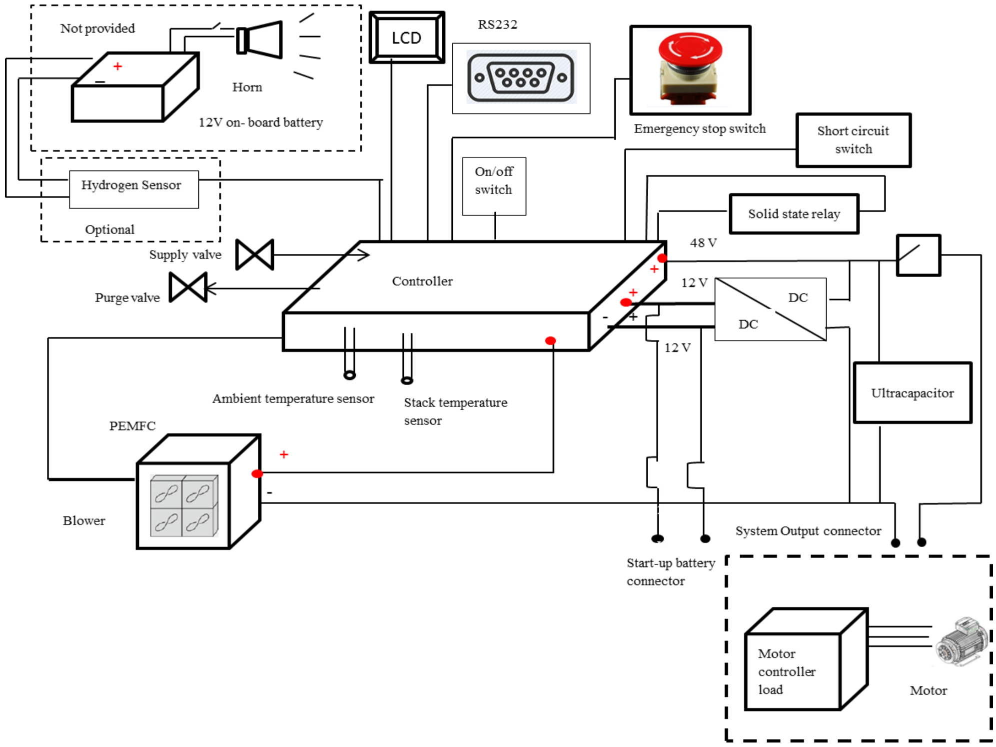


Figure 3.5 Electrical circuit diagram for H-1000XP [61]

Figure 3.5 shows electrical circuit diagram for H-1000XP. Hydrogen supplies to the PEMFC at 0.5 bars. In this system, there are two valves available. Supply valve is for hydrogen supply and purge valve is for purging out hydrogen when PEMFC is not in use to avoid damage on membrane. Pressure regulator usage is to control hydrogen supplied at constant pressure. Then, battery is being connected for startup the system and power on hydrogen sensor. Hydrogen will trigger alarm if there is leakage of hydrogen. After that, press switch for about 3 seconds until the system is on. Temperature sensor and blower are necessary to maintain stack temperature below than 65°C to avoid stack damage. The system connects to the laptop for monitoring of ambient temperature, stack power, battery voltage, stack temperature, stack voltage and stack current. H-1000XP set includes internal DC/DC converter is for regulating the output voltage of PEMFC controller at 12 V for the fuel cell controller to operate. Functions of controller in this system aforementioned in chapter 2 are for controlling stack temperature (below 65 °C), control stack purge rate, monitoring stack current and voltage, monitoring H_2 concentration, protecting stack from possible failures (stack low voltage (25 V), over current (50 A), over temperature protection (68 °C), control hydrogen supply and shut off, and communication with computer for data logging. Ultracapacitor can supply power output during system short circuiting which could enable system continuous operation without external power supply.

Electrical circuit diagram from user manual shows example for motor as a load. In this study, AC load which is bulb is being used as a load. Figure 3.6 shows electrical circuit diagram for supplying power to the AC load. External DC/DC converter is connected to output connecter to regulate the voltage at 36 V to supply to the DC/AC inverter from Swipower Company. DC/AC inverter inverts DC output voltage of PEMFC to AC voltage. DC input voltage range of inverter is between 30 V to 45 V (details in Appendices D).

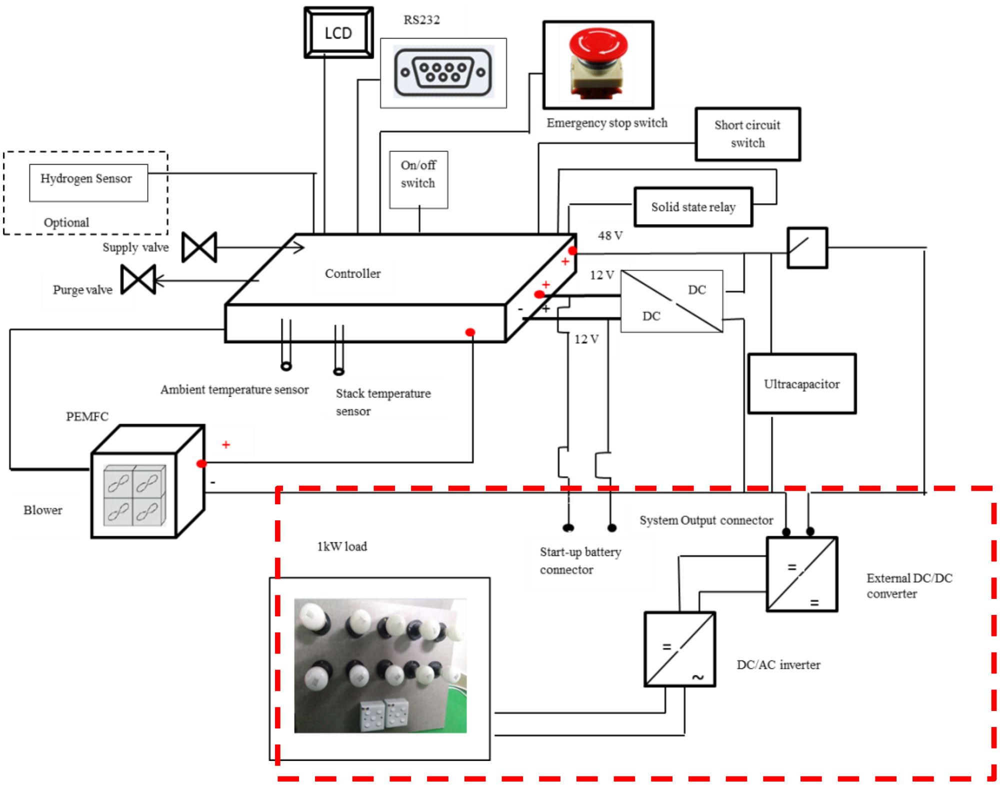


Figure 3.6 Electrical circuit diagram for H-1000XP with external DC/DC converter and DC/AC inverter [61]

3.2 Data Collection of Felda Sahabat

The two main export commodities in Sabah are petroleum and palm oil. Felda Sahabat which is located in east coast area is the largest palm oil plantation of Sabah. Map of major power station and grid supply in Sabah is attached at Appendix B. Even though gas turbine is the largest power generator in Sabah, it is different for Felda Sahabat. Based on data from Felda Engineering Sdn Bhd, the power generator that available in Felda Sahabat is diesel generator. Apart from diesel generator, based on report from Palm Oil Industries Sdn Bhd, Sahabat Biomass Power Plant which is used oil palm EFB to generate electricity up to 7.5 MW. Sahabat Biomass Power Plant, which can produce up to 55,000 tonnes of Carbon Emission Credits (CERs) per year, has started selling CERs to an European buyer since 2006 [62]. Felda Sahabat has all three potential of PV, biomass and OTEC. It is near to potentially develop OTEC area and it can be connected through land, air or water.

Felda Sahabat is located 100 km from Lahad Datu, Sabah. Total area of Felda Sahabat is 106,760 (hectare) which is consists of palm oil estate 105,053 (hectare) and residence area 1,707 (hectare). Number of houses available in Felda Sahabat is 800 houses. Figure 3.7 shows map of Sabah and location of Felda Sahabat. Felda Sahabat is chosen as study case area because it is near to OTEC power plant construction plan area. It is easy for transportation of hydrogen gas from OTEC power plant to land area.

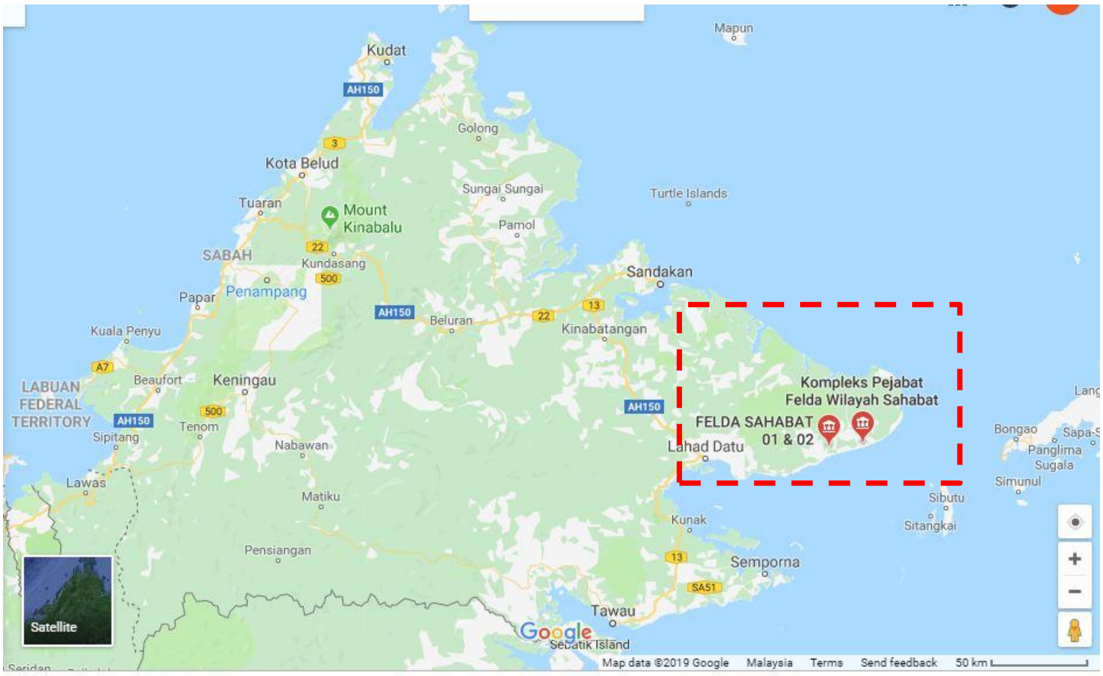


Figure 3.7 Location of Felda Sahabat [63]

Based on data provided by Felda Engineering Sdn Bhd, total diesel generator capacity available in Felda Sahabat is 10,785 kW. Table 3.2 shows list of diesel generators in Felda Sahabat. There are 10 stations available which are Stesen Janakuasa Bandar Sahabat or Desa Kencana (SJBS/DK), Stesen Janakuasa Anjung Tanah (SJAT), Stesen Janakuasa Cenderawasih (SJC), Stesen Janakuasa Baiduri Ayu (SJBA), Stesen Janakuasa Embara Budi (SJEB), Stesen Janakuasa Fajar Harapan (SJFH), Stesen Janakuasa Gemala Pura (SJGP), Stesen Janakuasa Hamparan Badai (SJHB), Stesen Janakuasa Jeragan Bestari (SJJB) and Stesen Janakuasa Kembara Sakti (SJKS). Normally, installation of diesel generator capacity is bigger than amount of required load. Load utilize from diesel generator power plant is 80%. Based on this data, estimation for suitable electrical power plant capacity for Felda Sahabat is 8,628 kW which is 80% from total diesel generator capacity available in Felda Sahabat. This value will be used for estimation specification for large PEMFC power plant.

Using diesel as fuel can harm environment. Besides that, noise from diesel generator is annoying to surrounding people. For future, demand for clean and renewable energy is increasing and diesel generator usage should be reduced. Due to this, off-grid power system using hydrogen fuel is good option to provide electricity to this area in the future.

Table 3.2 List of available diesel generator in Felda Sahabat [64]

No.	Station	Location	Model		
			Engine	Alternator	Capacity (kW)
1	SJBS/ DK	Bandar Sahabat	Cummins / VTA28G5	LEROY SUM	500
			Cummins / KTA38	MARATHON	800
			Cummins / KTA38	STANDFORD	800
			Cummins /KTA38	STANDFORD	800
TOTAL					2900
2	SJAT	Anjung Tanah	Cummins/ KTA19-G4	MARATHON	400
			Cummins/KTA19-G4	MARATHON	400
			Cummins/NTA855G2	LEROY SUM	250
			Cummins/NTA855G2	LEROY SUM	250
TOTAL					1300
3	SJC	Cenderawasih	Cummins / KTA38	STANDFORD	800
			Cummins / KTA38	MARATHON	800
			Cummins /VTA28G5	STANDFORD	500
			Cummins /VTA28G5	STANDFORD	500
TOTAL					2600
4	SJBA	Baiduri Ayu	Cummins/6CT8.3G	CBR128 (STDFD)	125
			Cummins/6CT8.3G	CBR128 (STDFD)	125
			Cummins/6CT8.3G	STANDFORD	125
			Cummins/6BT5.3G	STANDFORD	60
TOTAL					435

Table 3.2 Continued

No.	Station	Location	Model		
			Engine	**Alternator**	**Capacity (kW)**
5	SJEB	Embara Budi	Cummins/LTA10G3	MARATHON	200
			Cummins/LTA10G4	MARATHON	200
			Cummins/6CT8.3G	CBR128	125
			Cummins/6CT8.3G	CBR128	125
TOTAL					650
6	SJFH	Fajar Harapan	Cummins/6CT8.3G	STANDFORD	125
			Cummins/6CT8.3G	STANDFORD	125
			Cummins/NTA855G2	MARATHON	250
TOTAL					500
7	SJGP	Gemala Pura	Cummins/6CT8.3G	MARATHON	125
			Cummins/6CT8.3G	MARATHON	125
			Cummins/LTA10G4	MARATHON	200
TOTAL					450
8	SJHB	Hamparan Badai	Cummins/6CT8.3G	MARATHON	125
			Cummins/6CT8.3G	MARATHON	125
			Cummins/LTA10G4	MARATHON	200
TOTAL					450
9	SJJB	Jeragan Bistari	Cummins/6CT8.3G	MARATHON	125
			Cummins/6CT8.3G	MARATHON	125
			Cummins/LTA10G4	MARATHON	200
TOTAL					450
10	SJKS	Kembara Sakti	Cummins/KTA19-G4	MARATHON	400
			Cummins/KTA19-G4	MARATHON	400
			Cummins/NTA855G2	MARATHON	250
TOTAL					1050
GRAND TOTAL					10785

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Experimental Result of Small Scale Off-grid Power System

Figure 4.1 until Figure 4.6 show ambient temperature, stack temperature, battery voltage, stack power, stack current and stack voltage value at load value 0 W, 100 W, 200 W, 300 W, 400 W and 500 W. Please refer to Appendix E for location of ambient temperature sensor measurement.

Each steps in Figure 4.6 shows that load power increase by 100 W. Stack power increase when load power increase. Graph in Figure 4.6 shows that when load power increase, the step for PEMFC output power increase steeply. From this, it concludes that PEMFC is able to adjust quickly based on required load demand and cause no power outage for consumer side. When load power increase, more current derive from PEMFC stack and more hydrogen flow into the PEMFC to deliver more power. When load power demand change to 500 W, PEMFC output power become unstable and power drop as shown in Figure 4.6. This result indicate that maximum power that can be delivered by PEMFC H-1000XP is 400 W. It shows that PEMFC H-1000XP only can supply about 40% of rated power. This information is important as guideline to estimate electrical specification for bigger size system. Value of ambient temperature, stack temperature, battery voltage, stack current, stack voltage and stack power is tabulated in Table 4.1.

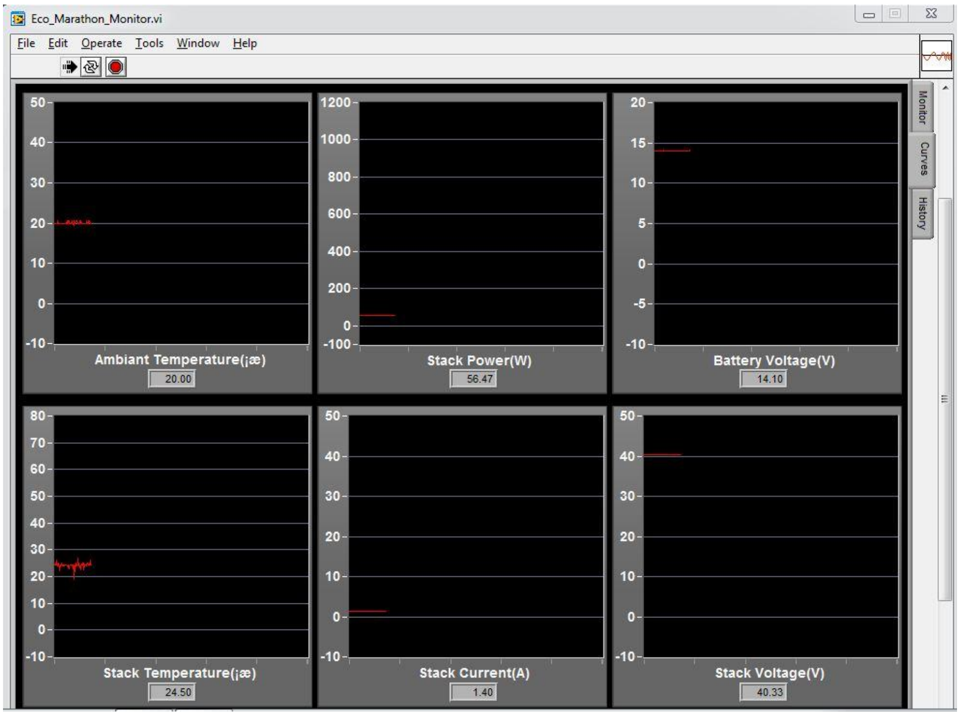


Figure 4.1 Stack power, stack current and stack voltage at 0 W

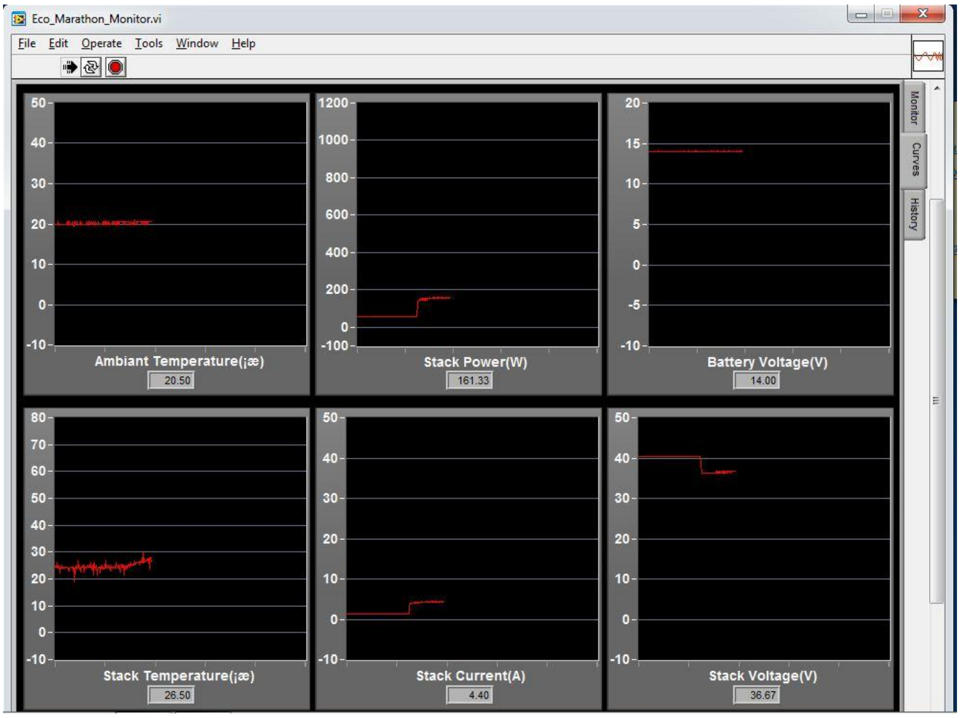


Figure 4.2 Stack power, stack current and stack voltage at 100 W

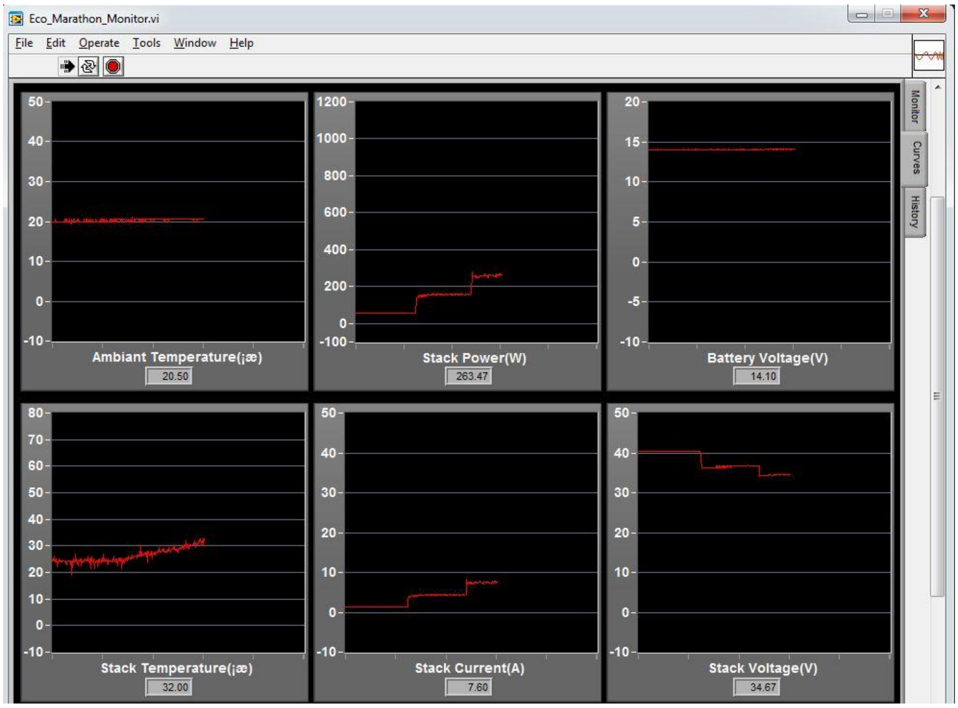


Figure 4.3 Stack power, stack current and stack voltage at 200 W

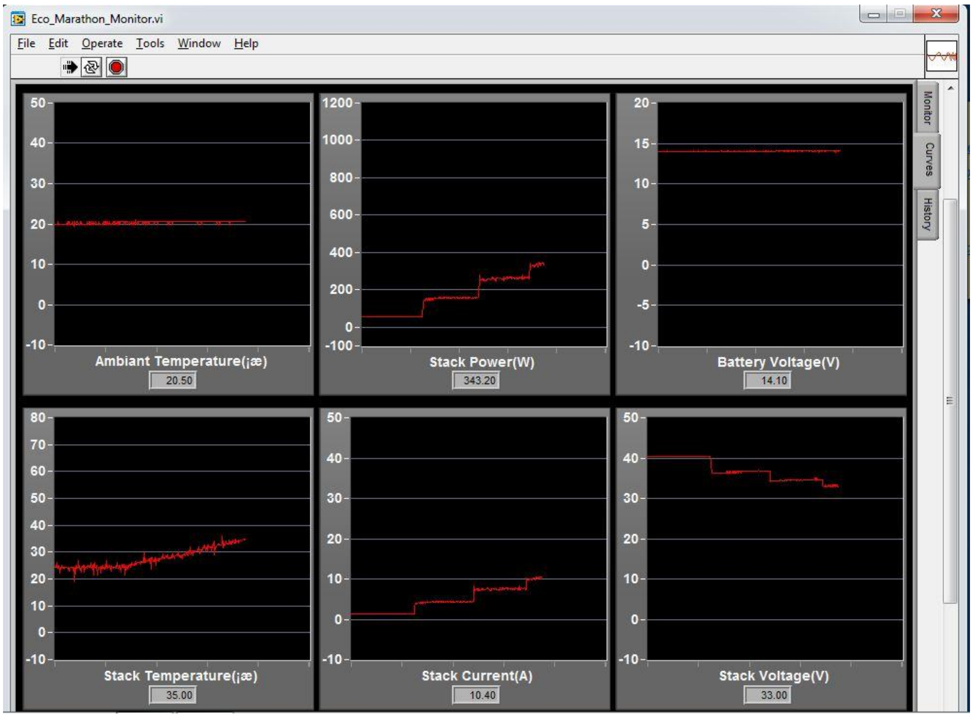


Figure 4.4 Stack power, stack current and stack voltage at 300 W

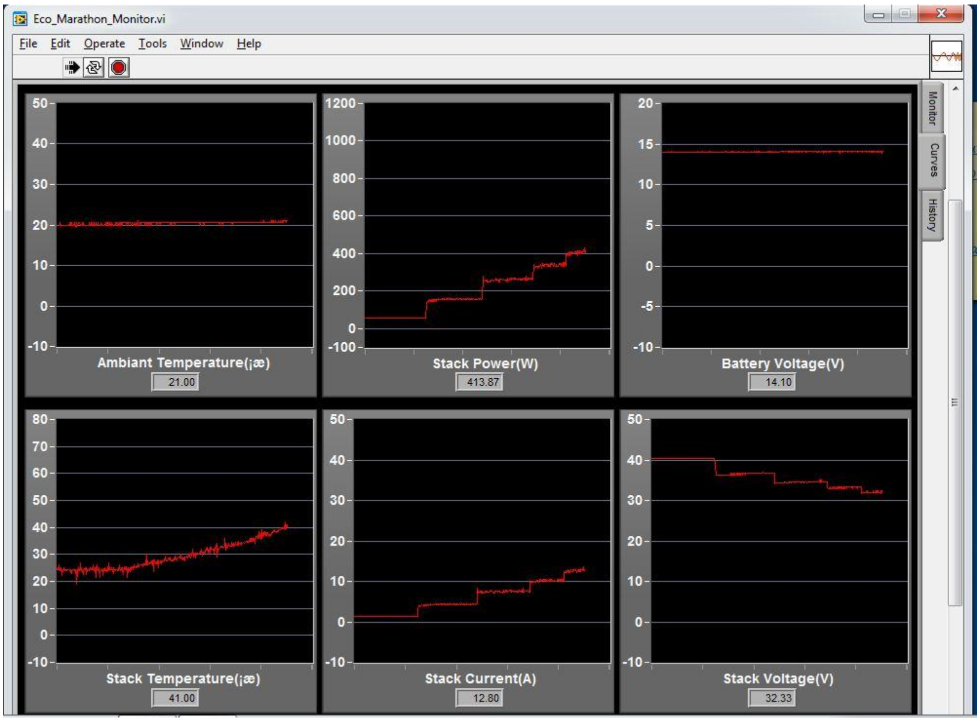


Figure 4.5 Stack power, stack current and stack voltage at 400 W

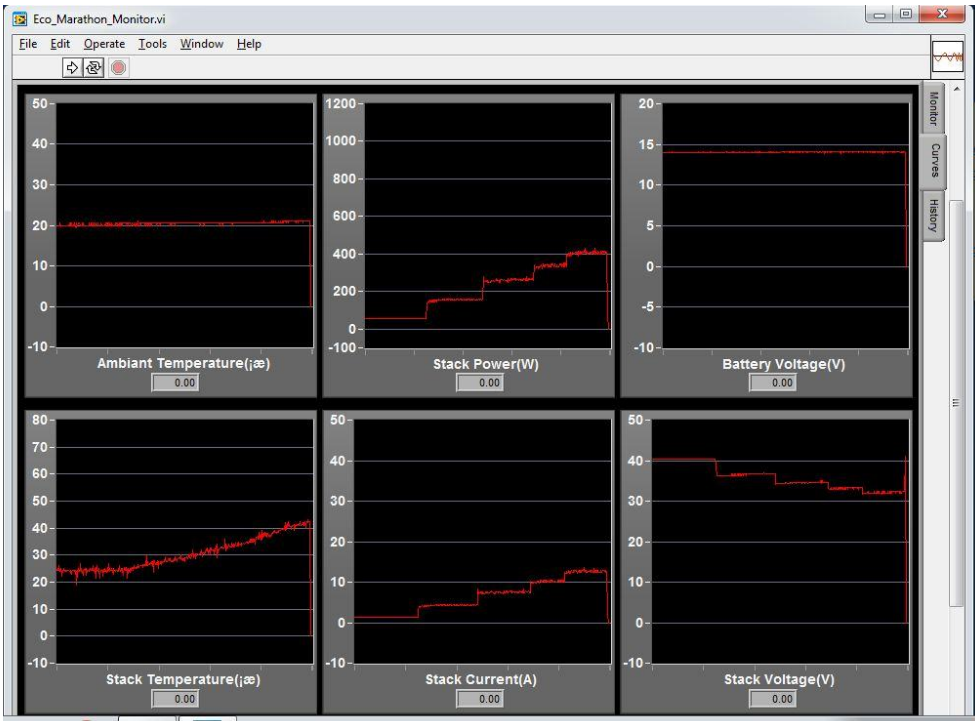


Figure 4.6 Stack power, stack current and stack voltage at 500 W

Table 4.1 Ambient temperature, stack temperature, battery voltage, stack current, stack voltage and stack power at different load power

Load Power (W)	**Ambient Temperature (°C)**	**Stack Temperature (°C)**	**Battery Voltage (V)**	**Stack Current (A)**	**Stack Voltage (V)**	**Stack Power (W)**
0	20.00	24.50	14.10	1.40	40.33	56.47
100	20.50	26.50	14.00	4.40	36.67	161.33
200	20.50	32.00	14.10	7.60	34.67	263.47
300	20.50	35.00	14.10	10.40	33.00	343.20
400	21.00	41.00	14.10	12.80	32.33	413.87
500	-	-	-	-	-	-

*No data recorded for load 500 W because PEMFC is not stable

4.2 OPEX for Small Scale PEMFC

Calculation doing based on project life time 25 years. Table 4.2 shows lifetimes assumption for system components. Lifetime for PEMFC is 1000 hours. Assume PEMFC is being operated 24 hours per day. One set of PEMFC can operated for about 41 days. In 25 years, PEMFC set need to be replaced for 222 times. Total cost of replacement is RM7, 276, 050. Lifetime for startup battery is 5 years. In 25 years, battery is needed to replace 5 times. Total cost for battery replacement in 25 years is RM360. For DC /DC converter and DC/AC inverter, assumes lifetime are 25 years, replacement cost in 25 years is RM 0.

Table 4.2 Lifetimes assumption for system components

Components	**Cost (RM)**	**Lifetime**	**Replacement Cost (RM/25 years)**
PEMFC H-1000XP set (1 kW)	32,775.00	1000 hours	7,276,050
Startup battery	72.00	5 years	360
DC/DC converter	57.70	25 years	0
DC/AC inverter	500.00	25 years	0
Total	33, 404.70		7, 276, 410

For operating PEMFC small scale off-grid power system, hydrogen consumption will be the biggest portion for the operational expenditure cost. Hydrogen consumption rate for 1 kW H-1000XP is 12 liter per minutes. In the experiment, a compressed hydrogen cylinder with capacity 47 liter is used. The purity of hydrogen is 99.99%. and cost of hydrogen cylinder is RM249.80. Number of hours for operating PEMFC at power rated 1 kW is 0.07 hours as shown in Equation (4.1). The cost of operating 1 kW PEMFC for 0.07 hours using only one cylinder is RM249.80. This is equivalent to RM3568.57 per kilowatt hour. This calculation based on price of hydrogen supplied at Kuala Lumpur during time of experiment.

$$\frac{47liter}{12liter \times 60minutes} = 0.07\ hours \quad (4.1)$$

Cost of hydrogen production from electrolysis process by 100 MW OTEC plant size is \$4.75/kg [44]. 1 kg of hydrogen is equal to 14.128 liter of hydrogen. Converting to liter, the price is \$0.336212 per liter. Using currency rate as 31st December 2018, RM1 is equal to \$0.24, price for hydrogen is RM1.40 per liter. This is price for hydrogen production at OTEC power plant. Assume the price sell to the customer is about 50% higher than production cost, the price become RM2.10 per liter. Assume the hydrogen supply from OTEC using the same cylinder size, for one tank of hydrogen, RM2.10 multiple with 47 liter, the price for one tank of hydrogen is RM98.70. By using hydrogen from OTEC, to operate 1 kW PEMFC for 0.07 hours is RM 98.70. To operate for one hour, RM98.70 divided with 0.07 hours, equivalent to RM1,410 per kilowatt hour. Assume PEMFC operates 24 hours, for one day cost of hydrogen consumption is RM33, 840. To operate in one year, RM33, 840 multiple with 365 days, cost for one year is RM12, 351, 600. To operate for 25 years, the cost will be RM308, 790, 000.

To operate small scale of off-grid system using PEMFC in 25 years, total cost is cost for components replacement in 25 years plus with hydrogen consumption for 25 years. Total cost for replacement is RM7, 276, 410 and total cost for hydrogen consumption is RM308, 790, 000, resulted in RM316, 066, 410 for total operational cost in 25 years.

4.3 Estimate Specification of 100 kW PEMFC

Based on data collection from Felda Sahabat, suitable net capacity for estimation capacity to develop power plant in Felda Sahabat is 8,628 kW. From experimental result, PEMFC can supply 40% electricity of PEMFC rated power. Using the information, to get net output electricity of 8,628 kW, 21,570 kW PEMFC should be developed. To design 21,570 kW PEMFC, the idea is stacked up biggest power rated PEMFC that is provided by Horizon Fuel Cell Company which is 5 kW. The flexibility of the modular PEMFC system allow designer to create PEMFC based on demand capacity. By developing PEMFC in modules, when one module down, other modules still can generate electricity. To duplicate specification for 21,570 kW PEMFC, calculation is done based on specification of 5 kW PEMFC as shown in Table 4.3 (follow details in Appendices C).

Table 4.3 Specification of 5 kW PEMFC

	Category	Value
	Type of fuel cell	PEM
Physical	Number of cells	120
	Dimensions	650mm x 350mm x 212mm
	Weight	stack 32.5 kg
Performance	Peak Power	5000W
	Rated current	0 - 70A @72V
	DC Voltage	60V - 72V
Fuel	Reactants	Hydrogen and air
	Composition	99.99% dry H_2
	H_2 pressure	0.50 - 0.65 bar
	Hydrogen Consumption @5000W or flowrate	65 SLPM(standard liter per minute)
Operation	External Temperature	5-30°C
	Max stack temperature	65°C
	Humidification	Self-humidified
	Cooling	Air
	Start up battery	24 V
Monitoring	RS232	System Status/Historical data

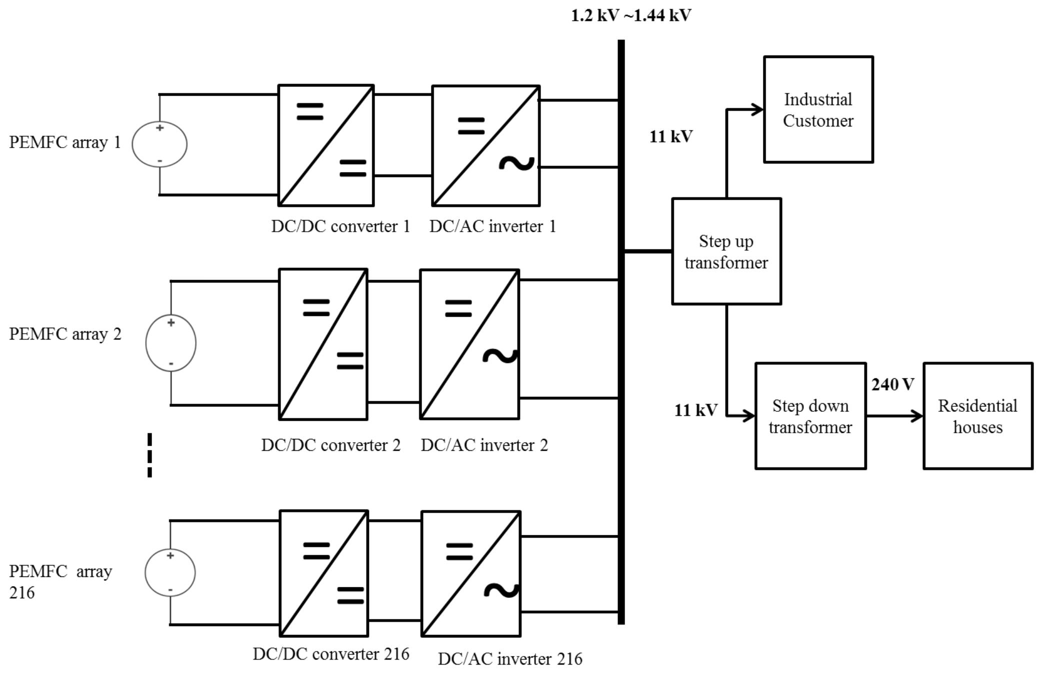


Figure 4.7 Modular system for 21, 570 kW PEMFC

To get 21,570 kW PEMFC, 216 units of modular 100 kW PEMFC can be developed. Figure 4.7 shows the modular system for 21,570 kW PEMFC which each modular capacity is 100 kW. Each PEMFC array consists of 20 units 5 kW PEMFC connected in series. Output voltage for 100 kW is 1.2 kV to 1.44 kV (details calculation refer to Equation (4.6) and Equation (4.7)). For distribution, output voltage can be step up to 11 kV using step up transformer to deliver electricity to the industrial customer which is palm oil mill in Felda Sahabat and can be step down to 240 V to supply electricity to the Felda Sahabat resident.

To get 100 kW PEMFC, 20 units of 5 kW PEMFC is needed as per shown in Equation (4.2). To get number of cells for 100 kW, number of cells for 5 kW PEMFC which is 120 cells multiple with 20 as shown in Equation (4.3). Thus, number of cells for 100 kW PEMFC is 2,400 cells.

$$100kW \div 5kW = 20 \text{ units PEMFC} \quad (4.2)$$

$$120\ cells\ \times 20 = 2{,}400\ cells \tag{4.3}$$

To calculate dimension for 100 kW PEMFC, dimension for 100 kW PEMFC is 20 times bigger than 5 kW PEMFC, calculation is done based on Equation (4.4) and total size is 385.84 m^3. Assume bigger size about 30% for the auxiliary component such as battery, DC/DC converter, DC/AC inverter and hydrogen supply, result for total size will be 501.592 m^3.

$$\begin{gathered} 20(0.65m) \times 20(0.35m) \times 20(0.212m) = \\ 13m \times 7m \times 4.24m \end{gathered} \tag{4.4}$$

$$20 \times 32.5\ kg\ = 650kg \tag{4.5}$$

Equation (4.5) shows calculation for weight. For voltage, total voltage will be 1200 V to 1440 V as per shown in Equation (4.6) and Equation (4.7).

$$60V\ \times\ 20 = 1200V \tag{4.6}$$

$$72V \times 20 = 1440V \tag{4.7}$$

For type of fuel cell, reactants, composition, H_2 pressure, external temperature, maximum stack temperature, humidification, cooling and monitoring system are remain the same with 5 kW PEMFC specification. 20 batteries with voltage 24 V is needed for startup. For hydrogen consumption, total amount is 1,300 Standard Liter Per Minute (SLPM) as per shown in Equation (4.8). Table 4.4 shows estimation specification for 100 kW PEMFC.

$$65\ SLPM \times 20 = 1{,}300SLPM \tag{4.8}$$

Table 4.4 Estimation specification for 100 kW PEMFC

	Category	**Value**
	Type of fuel cell	PEM
Physical	Number of cells	2,400
	Dimensions	501.592 m^3
	Weight	650 kg
Performance	Peak Power	100 kW
	Rated current	0-70A
	DC Voltage	1200V - 1440V
Fuel	Reactants	Hydrogen and air
	Composition	99.99% dry H_2
	H_2 pressure	0.50 - 0.65 bar
	Hydrogen Consumption @1MW or flowrate	1,300 SLPM (standard liter per minute)
Operation	External Temperature	5-35°C
	Max stack temperature	65°C
	Humidification	Self-humidified
	Cooling	Air
	Start up battery	24 V x 20
Monitoring	RS232	System Status/Historical data

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

From this study, several points are concluded and some recommendations for future work are being highlighted.

5.1 Conclusion

From this study, it can be concluded that experimental result using 1 kW H-1000XP shows that efficiency of the PEMFC small scale power system is 40%. For proposing the capacity of bigger scale of PEMFC off-grid power system to Felda Sahabat, 21,570 kW PEMFC off-grid power system is suitable to get net power output at 8,628 kW. Operational expenditure cost assumption for 1 kW PEMFC H-1000XP using hydrogen from OTEC for 25 years is RM316, 066, 410. Electrical specification of 1 modular 100 kW PEMFC output voltage and output current is 1.2 kV to 1.44 kV and 0 A to 70 A, respectively. 216 units of 100 kW modular PEMFC is required to get net output 8,628 kW for PEMFC off-grid installation proposal for Felda Sahabat, Sabah. This study can be baseline for Felda Sahabat and other organizations for developing PEMFC off-grid power system using hydrogen from OTEC in the future.

5.2 Recommendation

To calculate more accurate cost of implementation off-grid power system using PEMFC, cost of distribution cable, protection system, transformer for power distribution should be included. Monitoring system should be installed to monitor amount of hydrogen as proactive action to avoid hydrogen from being out of stack. Hydrogen supply is very important for PEMFC, because without hydrogen PEMFC cannot generate electricity.

Felda Sahabat should integrate biomass power plant with PEMFC as backup during biomass power plant maintenance. Instead of only using hydrogen supply from OTEC, study on how to utilize methanol from palm oil landfill should carry out as another alternative to fully utilize waste from palm oil production.

Study for implementation PEMFC as distribute generation to the houses area with low density of resident is good option to supply electricity in remote area in Sabah. Villagers should be trained to manage their own PEMFC at their house and this is practical because PEMFC is easy to operate and need no difficult maintenance to maintain the system. Integration of PEMFC with electrolyzer to produce hydrogen onsite is also good idea to remote area which are difficult to get hydrogen supply from outside.

With the flexibility to install PEMFC either for standalone or hybrid, it is recommended to utilize this technology for electricity generation when PEMFC and OTEC technology are matured enough to compete with conventional electricity generation in term of cost.

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Appendix A Website Photovoltaic Monitoring System by SEDA Malaysia

https://pvms.seda.gov.my/pvsystem/site/index?PlantSearch%5Bid%5D=&PlantSearch%5Bplant_type%5D=&PlantSearch%5Bcapacity%5D=&PlantSearch%5BsearchState%5D=14...

PVMS PV MONITORING SYSTEM | Dashboard | Catalogue | My Account | Logout (aida)

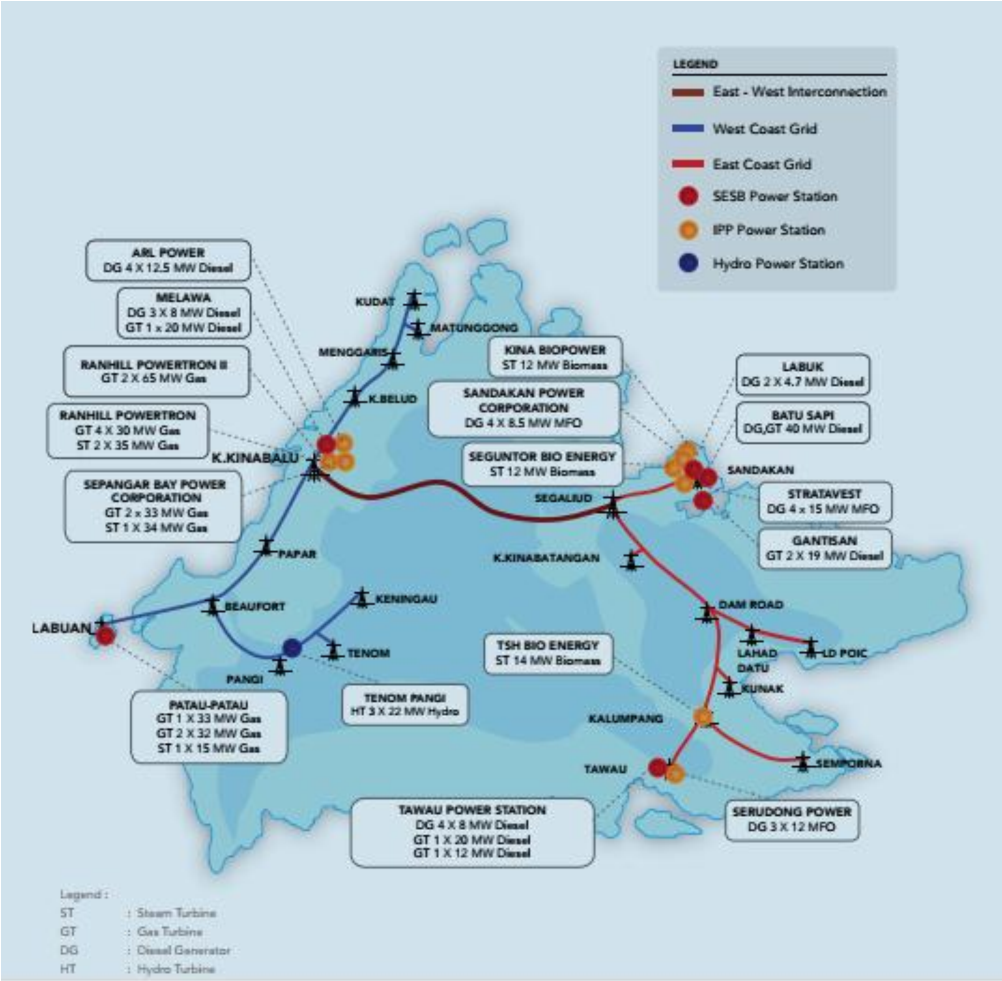
Photovoltaic Monitoring System

by SEDA Malaysia

Showing **1-5** of **6** items.

No.	Plant Name	Image	Plant Type	Capacity (kWp)	Location	Inverter Type	Module Type	Commission Date
			Select All	Select All	SABAH			
1	Plant #125		Community	24.000 kWp	SABAH, MALAYSIA	String	Mono Crystalline	23 Dec 2016
2	Plant #127		Community	24.000 kWp	SABAH, MALAYSIA	String	HIT	24 Nov 2015

Appendix B Major Power Station and Grid Supply in Sabah



Appendix C PEMFC Catalogue from Horizon Fuel Cell

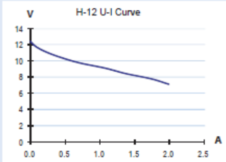
Horizon
Fuel Cell Technologies

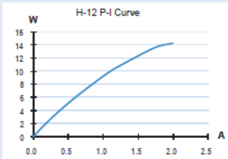
Semi-integrated 12W fuel cell system

Includes:
- *Integrated fan and casing*
- *12W stack with blower*

H-12
FCS-B12
12W

Type of fuel cell	PEM
Number of cells	13
Rated power	12W
Rated Performance	7.8V@1.5A
Purging valve voltage	6V
Blower voltage	5V
Reactants	Hydrogen and Air
Ambient temperature	5-30°C(41-86°F)
Max stack temperature	55°C(131°F)
Hydrogen pressure	0.45-0.55Bar
Humidification	Self-humidified
Cooling	Air (integrated cooling fan)
Stack weight (with fan & casing)	275g(±30g)
Stack size	75x47x70mm
Flow rate at max output	0.18L/min
Hydrogen purity	≥99.995% dry H2
Start up time	≤30s (ambient temperature)
Efficiency of system	40% at full power





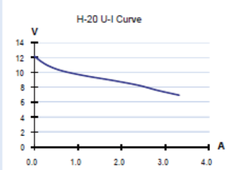

Controller

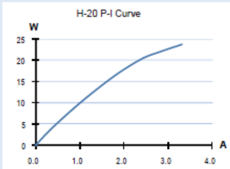
Semi-integrated 20W fuel cell system

Includes:
- *Miniature electronic valve*
- *Control electronics*
- *Integrated fan and casing*
- *Low voltage protection*
- *20W stack with blower*

H-20
FCS-B20
20W

Type of fuel cell	PEM
Number of cells	13
Rated power	20W
Rated Performance	7.8V@2.6A
Purging valve voltage	6V
Blower voltage	5V
Reactants	Hydrogen and Air
Ambient temperature	5-30°C(41-86°F)
Max stack temperature	55°C(131°F)
Hydrogen pressure	0.45-0.55Bar
Humidification	Self-humidified
Cooling	Air (integrated cooling fan)
Stack weight (with fan & casing)	275g(±30g)
Controller weight	90g(±10g)
Stack size	75x47x70mm
Flow rate at max output	0.28L/min
Hydrogen purity	≥99.995% dry H2
Start up time	≤30s (ambient temperature)
Efficiency of system	40% at full power





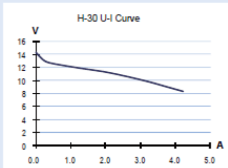

Controller

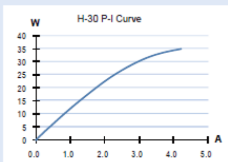
Semi-integrated 30W fuel cell system

Includes:
- *Miniature electronic valve*
- *Control electronics*
- *Integrated fan and casing*
- *Low voltage protection*
- *30W stack with blower*

H-30
FCS-B30
30W

Type of fuel cell	PEM
Number of cells	14
Rated power	30W
Rated Performance	8.4V@3.6A
Purging valve voltage	6V
Blower voltage	5V
Reactants	Hydrogen and Air
Ambient temperature	5-30°C(41-86°F)
Max stack temperature	55°C(131°F)
Hydrogen pressure	0.45-0.55Bar
Humidification	Self-humidified
Cooling	Air (integrated cooling fan)
Stack weight (with fan & casing)	280g(±30g)
Controller weight	90g(±10g)
Stack size	80x47x75mm
Flow rate at max output	0.42L/min
Hydrogen purity	≥99.995% dry H2
Start up time	≤30s (ambient temperature)
Efficiency of system	40% at full power





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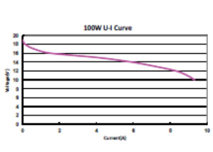
Horizon
Fuel Cell Technologies

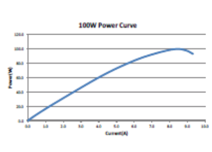
Semi-integrated 100W fuel cell system

Includes:
- *Connections/Tubing*
- *Electronic valves*
- *Electronic control box*
- *100W stack with blower*
- *Fuel cell ON/OFF switch*
- *SCU ON/OFF switch*

H-100
FCS-C100
100W

Type of fuel cell	PEM
Number of cells	20
Rated power	100W
Rated Performance	12V@8.3A
Hydrogen supply valve voltage	12V
Purging valve voltage	12V
Blower voltage	12V
Reactants	Hydrogen and Air
Ambient temperature	5-30°C(41-86°F)
Max stack temperature	65°C(149°F)
Hydrogen pressure	0.45-0.55Bar
Humidification	Self-humidified
Cooling	Air (integrated cooling fan)
Stack weight (with fan & casing)	1290g(±50g)
Controller weight	400g(±30g)
Stack size	118x104x94mm
Flow rate at max output	1.3L/min
Hydrogen purity	≥ 99.995% dry H2
Start up time	≤30s (ambient temperature)
Efficiency of system	40% @12V
Low voltage protection	10V
Over current protection	12A
Over temperature protection	65°C
External power supply	13V(±1V), 5A



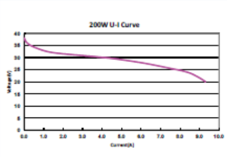


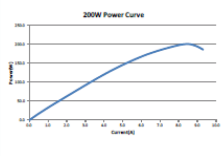
Semi-integrated 200W fuel cell system

Includes:
- *Connections/Tubing*
- *Electronic valves*
- *Electronic control box*
- *200W stack with blower*
- *Fuel cell ON/OFF switch*
- *SCU ON/OFF switch*

H-200
FCS-C200
200W

Type of fuel cell	PEM
Number of cells	40
Rated power	200W
Rated Performance	24V@8.3A
Hydrogen supply valve voltage	12V
Purging valve voltage	12V
Blower voltage	12V
Reactants	Hydrogen and Air
Ambient temperature	5-30°C(41-86°F)
Max stack temperature	65°C(149°F)
Hydrogen pressure	0.45-0.55Bar
Humidification	Self-humidified
Cooling	Air (integrated cooling fan)
Stack weight (with fan & casing)	2230g(±50g)
Controller weight	400g(±30g)
Stack size	118x183x94mm
Flow rate at max output	2.6L/min
Hydrogen purity	≥99.995% dry H2
Start up time	≤30s (ambient temperature)
Efficiency of system	40% @24V
Low voltage protection	20V
Over current protection	12A
Over temperature protection	65°C
External power supply	13V(±1V), 5A



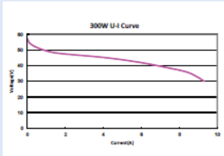


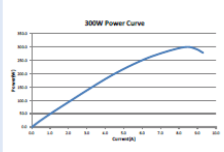
Semi-integrated 300W fuel cell system

Includes:
- *Connections/Tubing*
- *Electronic valves*
- *Electronic control box*
- *300W stack with blower*
- *Fuel cell ON/OFF switch*
- *SCU ON/OFF switch*

H-300
FCS-C300
300W

Type of fuel cell	PEM
Number of cells	60
Rated power	300W
Rated Performance	36V@8.3A
Hydrogen supply valve voltage	12V
Purging valve voltage	12V
Blower voltage	12V
Reactants	Hydrogen and Air
Ambient temperature	5-30°C(41-86°F)
Max stack temperature	65°C(149°F)
Hydrogen pressure	0.45-0.55Bar
Humidification	Self-humidified
Cooling	Air (integrated cooling fan)
Stack weight (with fan & casing)	2790g(±50g)
Controller weight	400g(±30g)
Stack size	118x262x94mm
Flow rate at max output	3.9L/min
Hydrogen purity	≥99.995% dry H2
Start up time	≤30s (ambient temperature)
Efficiency of system	40% @36V
Low voltage protection	30V
Over current protection	12A
Over temperature protection	65°C
External power supply	13V(±1V), 5A





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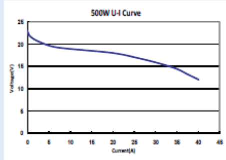
Horizon
Fuel Cell Technologies

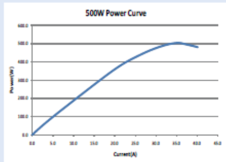
Semi-integrated 500W fuel cell system

Includes:
- *Connections/Tubing*
- *Electronic valves*
- *Electronic control box*
- *500W stack with blower*
- *Fuel cell ON/OFF switch*
- *SCU ON/OFF switch*

H-500
FCS-C500
500W

Type of fuel cell ....PEM
Number of cells... 24
Rated power...500W
Rated Performance......................... 14.4V@35A
Hydrogen supply valve voltage.................. 12V
Purging valve voltage................................ 12V
Blower voltage...12V
Reactants............................. Hydrogen and Air
Ambient temperature............. 5-30°C(41-86°F)
Max stack temperature.................65°C(149°F)
Hydrogen pressure..................... 0.45-0.55Bar
Humidification.......................... Self-humidified
Cooling.................. Air (integrated cooling fan)
Stack weight (with fan & casing)... 2520g(±50g)
Controller weight........................ 400g(±30g)
Stack size.......................... 130x268x123mm
Flow rate at max output....................... 6.5L/min
Hydrogen purity.................. ≥99.995% dry H2
Start up time.........≤30s (ambient temperature)
Efficiency of system...................40% @14.4V
Low voltage protection............................ 12V
Over current protection..............................42A
Over temperature protection......................65°C
External power supply................ 13V(±1V), 5A



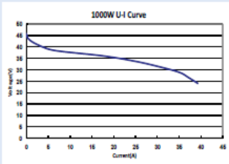


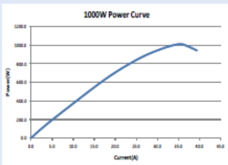
Semi-integrated 1000W fuel cell system

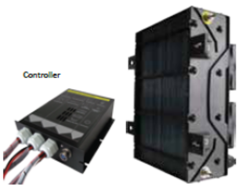
Includes:
- *Connections/Tubing*
- *Electronic valves*
- *Electronic control box*
- *1000W stack with blower*
- *Fuel cell ON/OFF switch*
- *SCU ON/OFF switch*

H-1000
FCS-C1000
1000W

Type of fuel cell ....PEM
Number of cells... 48
Rated power...1000W
Rated Performance.........................28.8V@35A
Hydrogen supply valve voltage.................. 12V
Purging valve voltage................................12V
Blower voltage...12V
Reactants............................. Hydrogen and Air
Ambient temperature............. 5-30°C(41-86°F)
Max stack temperature.................65°C(149°F)
Hydrogen pressure..................... 0.45-0.55Bar
Humidification.......................... Self-humidified
Cooling.................. Air (integrated cooling fan)
Stack weight (with fan & casing)..... 4kg(±100g)
Controller weight......................... 400g(±30g)
Stack size.......................... 219x268x123mm
Flow rate at max output........................13L/min
Hydrogen purity.................. ≥99.995% dry H2
Start up time.........≤30s (ambient temperature)
Efficiency of system...................40% @28.8V
Low voltage protection............................ 24V
Over current protection..............................42A
Over temperature protection......................65°C
External power supply............13V(±1V), 5A-8A





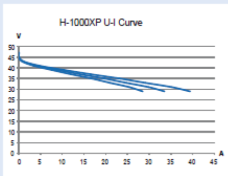


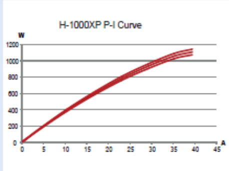
Semi-integrated 1kW fuel cell system

Includes:
- *LCD display*
- *Hydrogen sensor*
- *Ambient temperature sensor*
- *DC-DC converter*
- *Ultra capacitor bank*
- *Electronic control box*
- *Electronic valves*
- *RS232 connector*
- *Blower controller*
- *Start up battery connector*
- *Software(optional)*
- *ON/OFF switch*
- *Emergency stop switch*
- *PU tubing*

H-1000XP
1000W
Extra Performance

Type of fuel cell ....PEM
Number of cells... 50
Rated power...1000W
Rated Performance.........................30V@33.5A
Hydrogen supply valve voltage.................. 12V
Purging valve voltage................................12V
Blower voltage...12V
Reactants............................. Hydrogen and Air
Ambient temperature............. 5-35°C(41-95°F)
Max stack temperature.................65°C(149°F)
Hydrogen pressure..................... 0.45-0.55Bar
Humidification.......................... Self-humidified
Cooling.................. Air (integrated cooling fan)
Stack weight (with fan & casing)..... Approx.5kg
Controller weight........................ Approx.1.9kg
Stack size.......................... 264x203x104mm
Flow rate at max output......................12.5L/min
Hydrogen purity......................≥99.99% dry H2
Start up time..≤30s
Efficiency of system........ 48%@ 30V LHV (net)
Low voltage protection............................ 25V
Over current protection..............................50A
Over temperature protection......................68°C
Start up battery..12V





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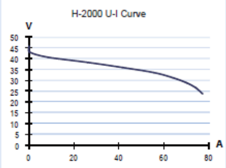
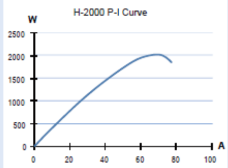
Semi-integrated 2000W fuel cell system

Includes:
- *Connections/Tubing*
- *Electronic valves*
- *Electronic control box*
- *2000W stack with blower*
- *Fuel cell ON/OFF switch*
- *SCU ON/OFF switch*
- *LCD display*

H-2000
FCS-C2000
2000W

Type of fuel cell ....PEM
Number of cells.. 48
Rated power...2000W
Rated Performance........................ 28.8V@70A
Hydrogen supply valve voltage.................. 12V
Purging valve voltage................................. 12V
Blower voltage..12V
Reactants............................... Hydrogen and Air
Ambient temperature............. 5-30°C(41-86°F)
Max stack temperature..................65°C(149°F)
Hydrogen pressure..................... 0.45-0.55Bar
Humidification.............................Self-humidified
Cooling................... Air (integrated cooling fan)
Stack weight (with fan & casing)....10kg(±200g)
Controller weight........................ 2500g(±100g)
Stack size............................. 303x350x183mm
Flow rate at max output......................... 26L/min
Hydrogen purity..................... ≥99.995% dry H2
Start up time..........≤30s (ambient temperature)
Efficiency of system....................40% @28.8V
Low voltage protection.............................. 24V
Over current protection..................................90A
Over temperature protection......................65°C
External power supply............13V(±1V), 5A-8A



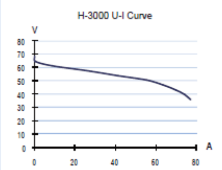


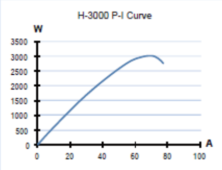
Semi-integrated 3000W fuel cell system

Includes:
- *Connections/Tubing*
- *Electronic valves*
- *Electronic control box*
- *3000W stack with blower*
- *Fuel cell ON/OFF switch*
- *SCU ON/OFF switch*
- *LCD display*

H-3000
FCS-C3000
3000W

Type of fuel cell ....PEM
Number of cells..72
Rated power...3000W
Rated Performance........................43.2V@70A
Hydrogen supply valve voltage..................12V
Purging valve voltage.................................12V
Blower voltage..12V
Reactants............................... Hydrogen and Air
Ambient temperature............. 5-30°C(41-86°F)
Max stack temperature..................65°C(149°F)
Hydrogen pressure..................... 0.45-0.55Bar
Humidification.............................Self-humidified
Cooling...................Air (integrated cooling fan)
Stack weight (with fan & casing)....15kg(±200g)
Controller weight........................2500g(±100g)
Stack size............................ 418x350x183mm
Flow rate at max output..........................39L/min
Hydrogen purity..................... ≥99.995% dry H2
Start up time......... ≤30s (ambient temperature)
Efficiency of system.................. 40% @43.2V
Low voltage protection.............................. 36V
Over current protection................................. 90A
Over temperature protection...................... 65°C
External power supply............13V(±1V), 5A-8A



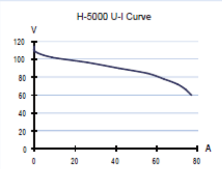


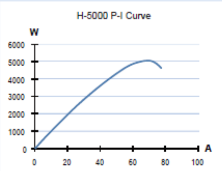
Semi-integrated 5000W fuel cell system

Includes:
- *Connections/Tubing*
- *Electronic valves*
- *Electronic control box*
- *5000W stack with blower*
- *Fuel cell ON/OFF switch*
- *SCU ON/OFF switch*
- *LCD display*

H-5000
FCS-C5000
5000W

Type of fuel cell ....PEM
Number of cells..120
Rated power...5000W
Rated Performance......................... 72V@70A
Hydrogen supply valve voltage..................12V
Purging valve voltage.................................12V
Blower voltage..24V
Reactants............................ Hydrogen and Air
Ambient temperature............. 5-30°C(41-86°F)
Max stack temperature..................65°C(149°F)
Hydrogen pressure..................... 0.45-0.55Bar
Humidification.............................Self-humidified
Cooling...................Air (integrated cooling fan)
Stack weight (with fan & casing)... 30kg(±200g)
Controller weight........................2500g(±100g)
Stack size.......................... 650x350x212mm
Flow rate at max output..........................65L/min
Hydrogen purity..................... ≥99.995% dry H2
Start up time......... ≤30s (ambient temperature)
Efficiency of system.................... 40% @72V
Low voltage protection..............................60V
Over current protection..................................90A
Over temperature protection...................... 65°C
External power supply.......... 24V(±1V), 8A-12A





www.horizonfuelcell.com

Appendix D Specification of Inverter

1. Product introduction:

This inverter uses the intelligent IC control produced by the company. The circuit has been very mature and stable. The use of high-quality circuit board and parts can ensure product quality and high performance. The machine's output waveform is pure sine wave, and it can be applied to any load. It has sound protection functions (including overload protection, overcurrent protection, high temperature protection, short circuit protection, battery reverse connection protection, battery high and low voltage protection, built-in fuse protection, etc.). The volume of the machine is very compact and portable.

2. Product model:

For example: SP12/220-1000

12 ——Nominal input DC voltage (Vdc)

220 —— Nominal output sine wave voltage (Vac)

1000——Nominal output power (W)

3. Applicable scope:

3.1 Vehicle: the vehicle battery is used to supply power for and drive Laptop/car vacuum/cell phone charging;

3.2 Ship: the ship battery is used to supply power for and drive conventional small appliances;

3.3 Household: for areas with frequent power outages and the battery is used to supply power for and drive conventional small appliances;

3.4 Field expedition: the use of standby battery for supplying power for and driving small conventional household appliances is more portable than the generator;

3.5 Environmentally-friendly energy use: with solar or wind power generation system, a stable AC power can be provided

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for electrical equipment;

3.6 Other: various occasions using mains supply

4. Input characteristics:

4.1 Rated input voltage: 12VDC/24VDC/36VDC/48VDC/60VDC/72VDC/96 VDC/110 VDC

4.2 Input voltage range: 10-15VDC/20-30VDC/30-45VDC/40-60VDC/47-70VDC/60-90VDC/80-120VDC/85-127VDC

4.3 Standby input power: <20W

5. Output characteristics:

5.1 Rated output power: 150W/300W/500W/600W/1000W/1200W1500W/2000W/2500W/3000W/3200W/4000W5000W/6000W/8000W

5.2 Peak output power: 2 times the rated power

5.3 Output voltage: 220VAC±5%

5.4 Output frequency: 50Hz±1Hz

5.5 Output waveform: Pure sine wave

5.6 Conversion efficiency: Conversion efficiency≥85%

6. Protection characteristics:

6.1 Input fuse: 40A*2/20A*2/10A*2

6.2 Input low voltage protection: 10V、20V、40V

6.3 Input high voltage protection: 15V、30V、60V

6.4 Low input voltage alarm: 10~10.5V、20~21V、40~42V

6.5 Output overload protection

6.6 Output short circuit protection

6.7 Temperature Protection: >70℃

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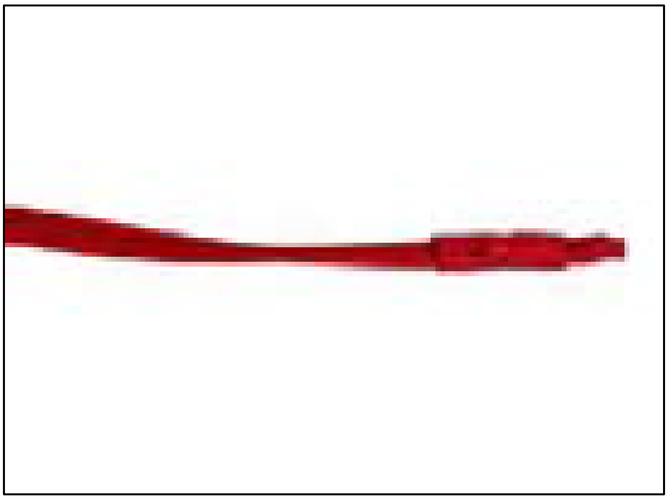
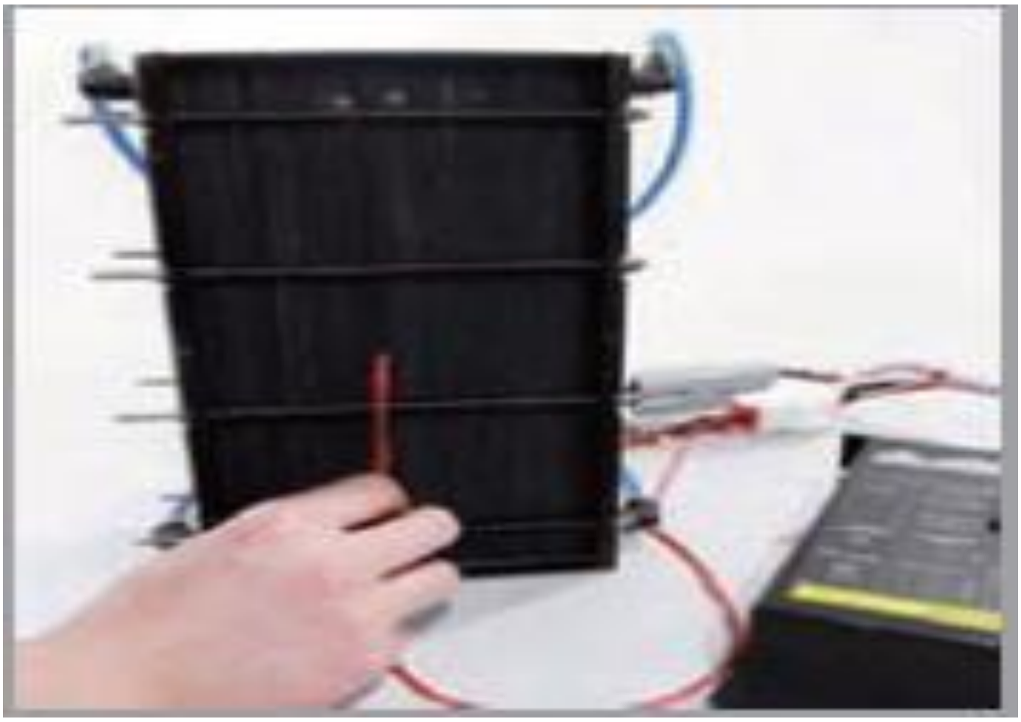
Appendix E   Ambient Temperature Sensor

Ambient temperature sensor



Ambient temperature sensor

It senses the ambient temperature.The sensor should be place opposite to the blower side of the fuel cell stack.



Please place the ambient temperature sensor opposite to the blower side of the stack. The place where the air comes in.

Appendix F   PEMFC H-1000XP Controller