Evaluation of the Solar Hybrid Systems for Rural Schools in Sabah, Malaysia

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1 INTRODUCTION

1.1 Overview

Malaysia has considerable number of widely deployed small rural areas. Most of these areas still lack of utilities such as power supply, water, communication and proper road access. This is due to the geographical condition of the location which make the investment cost to provide grid connected power supply, clean water treatment system, communication infrastructures, road access and other utilities are too expensive and not cost effective.

In line with the government's aspiration to utilize and develop more renewable energy by 2010 and to ensure that more rural areas will get benefit from the electricity supply program from renewable energy technology, the Ministry of Education (MOE) has initiated the Solar Hybrid System for Rural Schools in Sabah Project. The first phase was started in 2008 and the aimed was to give alternative electricity solution to 78 rural schools in Sabah using Solar Hybrid System.

1.2 Objectives

The main objectives of this master thesis is to study the impact of the rural electrification programme using Solar Hybrid System on the learning environment and daily lifestyle of the teachers and students at the rural schools in Sabah, Malaysia.

In order to evaluate the main objectives, the specific objectives of this study can be described as follows:

a) Study and analyze the impact of the Solar Hybrid System on the following aspects:
   i) The Malaysian renewable energy policies and strategies for rural education development;
   ii) The users experience before and after the system was installed;
   iii) The affect of the system on their lifestyle and the learning environment;
   iv) The users knowledge of renewable energy especially the Solar Hybrid System before and after the installation was made;
   v) The importance and potential of the system in education and social sense for rural area school and indirectly for the community as well.

b) Study and analyze the technical and the economical aspects of the system:
   i) System design and daily operation;
   ii) Reliability of the system using the Loss of Loads, Solar Fraction and Performance Ratio methods;
   iii) Economical aspect of using the solar hybrid system.

1.3 Methodology

This study used quantitative and qualitative methods in determining the impact of the Solar Hybrid System to the end users and to evaluate the system performance. The specific and suitable methods were developed to achieve the objectives as listed in the previous section.

1.3.1 Impact on the Solar Hybrid System

In order to identify and analyse the impact of the Solar Hybrid System, a set of structured questionnaire was made and then face to face interviews were conducted to the selected respondents, which are the teachers and the students of the selected schools. The questionnaires were made in two sets; ie, for teachers and students respectively. The questionnaire was developed to ensure that the impact of the system can be analyzed base on;

a) Comparison of the users experience before and after the system was installed and how does the system affect their lifestyle and the learning environment.
b) Comparison of the users' knowledge of renewable energy especially the Solar Hybrid System before and after the installation was made.
c) Any load management strategies which are being exercised by the users.
d) Users' opinion on how the system can benefit the entire community should the same system implemented for the village as well.

1.3.2 Implementation and operation of the Solar Hybrid System

The second part of the methodologies will determine the Solar Hybrid System performance technically and economically. The results of the analysis will be used to support the analysis done in the first part; ie, the impact of the technology diffusion on the rural development, specifically the rural schools environment.

1.3.2.1 Design and Actual Load Analysis

The design and actual load analysis will compare the design load profile and the actual load profile (average). The comparison is expected to give some idea(s) and what recommendation(s) can be made to the JKR project management team for the next project. This will help to minimise error(s) and mistake(s) during the design stage which may affect the performance of the system once the system is in operation. The analysis also can be used to understand the end users behaviour and how the system affects their daily power consumption.

1.3.2.2 System Operation Analysis

The system operation analysis will answer the sustainability and reliability issues of the system. The measurement data recorded by the online monitoring system; ie, JKR Supervisory Control and Data Acquisition System (JSCADA) are used to analyze the system performance based on;

a) The system loss of load
b) The system solar fraction
c) The system performance ratio

The results will be compared with the Homer simulation according to the actual system specification.

1.3.2.3 Economic Analysis

The economic analysis includes both costs and benefits of the system. Parameters like investment cost, operating cost and levelized cost of energy are used to measure the beneficial of the system as compared to the conventional diesel generator set.

1.4 Organization of the Thesis

The following chapter explains the Malaysian government policies and strategies in promoting renewable energy in the country. The chapter describes how renewable energy policy is used to improve education in the rural areas. Chapter 3 contains information of the Solar Hybrid System and the user energy demand. The measurement and simulation tools that were used to support this study are described in Chapter 4. While the result and analysis of the system can be found in Chapter 5. Finally, the conclusion and recommendation of the system are in the Chapter 6 and Chapter 7 respectively.

2 GREEN TECHNOLOGY FOR EDUCATION IN RURAL AREAS

2.1 Overview

Figure 2.1 : Malaysia and its neighbour countries in South East Asia

Malaysia is entirely equatorial (at Lat: 3.164° N, Long: 101.7° E). The ambient temperature remains uniformly high throughout the year, between 27 and 33°C, with an average daily solar radiation of 4,500 Wh per square metre a day and an average daily sunshine duration of about 12 hours. Generally, Malaysia has two seasons which are dry season from May to September and Rainy season from November to March every year. Most locations have a relative humidity of 80–88%, rising to nearly 90% in the highland areas and never falling below 60%.

The solar radiation in Malaysia is high by world standards. Even in Kuala Lumpur, a PV system receives 30% more energy than an equivalent system in Germany. Solar radiation varies from its lowest in the Klang Valley (Kuala Lumpur, Petaling Jaya) to Penang in the peninsular (Georgetown, northwest coast) and Kota Kinabalu in Sabah (East Malaysia), where the highest values have been measured.

Despite the abundant resource, solar PV applications in Malaysia are limited to mainly standalone PV systems, especially for rural electrification where the systems receive a significant subsidy. Other minor applications include telecommunication, street and garden lighting, and autonomous energy for parking ticket dispensing machines.

2.2 Malaysian Energy Policy Related With Renewable Energy

The power generation in Malaysia is still very much dependant on the conventional resources. Oil, natural gas and coal are the dominant resources to generate electricity for the nation. Whereas the main renewable energy that contributes to the power generation is the hydroelectric which contribute 18% of the total generated capacity.

Electricity in Malaysia is supplied by three utility companies which run the services in three different regions. Tenaga Nasional Berhad (TNB) operates in Peninsular Malaysia, Sarawak Electricity Supply Company (SESCO) serves electricity for Sarawak state and Sabah Electricity Sendirian Berhad (SESB) is the provider for Sabah state.

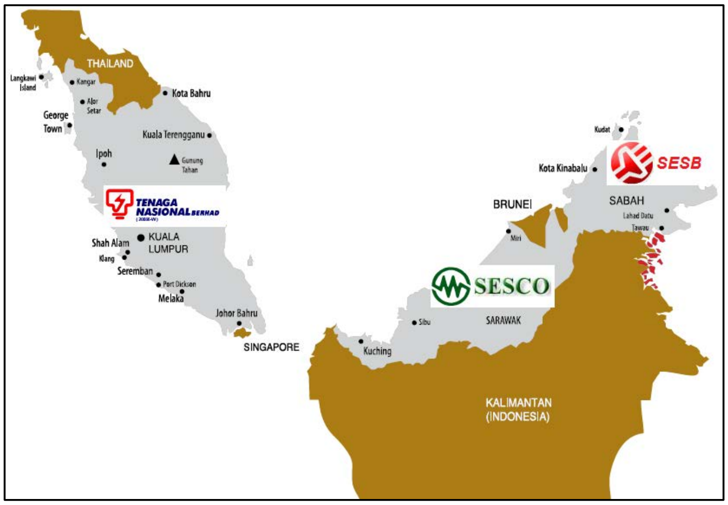


Figure 2.2 : The electricity utility companies in Malaysia. (Source : [15])

Only during the Eight Malaysia Plan (2001-2005) and the Ninth Malaysia Plan (2006-2010), the government had taken a serious action in making the sources from renewable energy as the fifth major ‘fuel’ resources. This includes biomass, solar, hydro and wind energy. It is expected that by the year 2010, a total of 300MW of installed power capacity will be produced by the renewable energy resources.

2.2.1 Malaysian Green Technology Policy

The effort continues when the government announced the National Green Technology Policy on the 24th July 2009 which shall be a driver to accelerate the national economy and promote sustainable development [1]. There are four pillars that will strengthen the policy which are:

a) Energy – seek to attain energy independence and promote efficient utilisation;
b) Environment – conserve and minimize the impact on the environment;
c) Economy – enhance the national economic development through the use of technology; and
d) Social – improve the quality of life for all.

The success of the policy is very much dependant on the National Key Indicators which are a set of criteria to measure the performance of various Government ministries and agencies in implementing renewable energy in Malaysia. The indicators are categorized into three elements which are;

a) Environment
  - Initial reduction in the rate of increase of GHG emission and subsequently progressing towards reduction in the annual GHG emission;
  - Progress of the rise in ranking of environmental performance by 2030; and
  - Improvement in air quality and river quality.

b) Economy
  - The Green Technology industry contributes a significant value and percentage of the National GDP;
  - Sizeable amount of investments are made in Green Technology industry through foreign direct investments (FDIs) and domestic direct investments (DDIs);
  - Increased number of certified Green industries and revenue in the country;
  - The Green Technology industry creates increasing number of jobs in the manufacturing and services sectors, as well as SMEs/SMIs; and
  - Increasing values of spin-off and supporting industries from the Green Technology industries.

c) Social
  - More cities, townships and communities are embracing Green Technology and are being classified as Green Townships.
  - More Malaysians appreciate Green Technology and Green Technology culture becomes a part of their lives; and
  - Improved quality of life in Malaysia.

The commitment to reduce the Green House Gasses (GHG) level up to 40% in the year 2020 as compared to 2005 level, announced by the Malaysian Prime Minister; Dato' Sri Najib Razak, during the United Nation Climate Change Conference (COP 15) in Copenhagen in December 2009, will help in making the policy a success. However, the commitment is subject to assistance from developed countries, upon receiving transfer of technology and adequate financing from the developed world. For record, Malaysia emitted 187 million tonnes of GHG or 7.2 tonnes per capita in year 2006.

2.2.2 Electricity in Rural Area

Apart from making renewable energy as among the main 'fuel' resources, the government also concern on the numbers of rural areas that still are not electrified by the national grid. The country has considerable numbers of widely deployed small rural areas [2]. Most of these areas still lack of utilities such as power supply, water, communication and proper road access. This is due to the geographical condition of the location which make the investment cost for providing a grid connected power supply, clean water treatment system, communication infrastructures, road access and other utilities are too expensive and not cost effective.

There was an overall improvement in the productivity and efficiency of electricity supply services in Malaysia [3]. It is predicted that in 2010, 95.1% of the area in Malaysia will be connected by grid electricity as compared to 92.9% in 2005. However, Sabah still has the most areas that do not have electricity from the grid network as shown in figure below.

Region	2000 [2]	2005	2010
Peninsular Malaysia	97.5	98.6	98.8
Sabah	67.1	72.8	80.6
Sarawak	66.9	80.8	89.6
Malaysia	**89.5**	**92.9**	**95.1**

Source: Economic Planning Unit and Ministry of Rural and Regional Development.

Figure 2.3 : Electricity coverage by region (Source :[3])

To date, most of the rural areas that do not have electricity from the grid use diesel generator as the main power supply, either decentralized or centralized generator. The cost of energy to supply the electricity using this method is very much dependent on the uncertainty of the global oil price and the price in the rural area can be very much higher as compared to the oil price in the city. The diesel selling price in Malaysia is fixed at € 0.34 per litre, while the difference in price as compared to the global diesel price is subsidised by the government. As reported in [14], the government spend €0.05/litre (RM0.30/litre)[1] on fuel subsidy

2.2.3 Renewable Energy Related Agencies

In Malaysia, there are several ministries and agencies that are related in the rural area development. Ministry of Energy, Green Technology and Water, Malaysian Energy Commission and Malaysian Energy Centre are the policy formulator and service regulator in assisting the government and industries to develop renewable energy in line with the government objectives.

Ministry of Rural and Regional Development is responsible in forming a progressive rural community through strengthening the human capital, infrastructure and economy. The scope of infrastructure includes electricity, road, water and social amenities. The ministry controls a fund called the Malaysia Electricity Supply Industry Trust Account (MESITA) fund which provides financial assistance for rural electrification, energy efficiency and renewable energy projects. The fund is in part created through Independent Power Producers (IPP) and Malaysian utility TNB Generation, who contribute 1% of their annual audited revenue to the fund. The technologies used include Solar Home System (SHS), Solar Hybrid System (combination of solar, wind and diesel generator) and diesel generator.

[1] At present, the currency value of the nation is at ~ RM4.98 for every €1.00

Besides the said ministries and agencies which contribute the biggest role in implementing renewable energy in the country, other ministries like Ministry of Education and Ministry of Health also give contribution in electrifying the rural areas with renewable energy, but they are limited within their own boundaries like schools and rural clinics.

2.3 National Education Policy and Plans

The nation's human capital is the key determinants of Malaysia's future success to achieve knowledge-based economy. The human capital will increase the productivity level to face the challenges in the new millennium. The agenda is to build and enhance the human capital that will be the medium of the national education system. In 2007, the nation ranked 66th in the world with 0.829 Human Development Index (HDI), an increment of 0.004 as compared to year 2006 [10]. Therefore the national education policy for the Ninth Malaysian Plan (2006-2010) has been planned in cooperating among others to improve the primary schools especially in rural areas, to bridge the education gap, and also to enhance the teachers' profession.

2.3.1 Infrastructure Allocation

Out of more than 10,000 schools in Malaysia; 809 schools do not have 24-hour electricity supply which located mostly in Sabah and Sarawak. Therefore, in the Ninth Malaysian Plan (2006-2010), the government has allocated a total of RM1.15 billion to improve and enhance rural school facilities like electricity, water system, Information and Communication Technology (ICT) and computer lab, road access, canteen etc, primarily in Sabah and Sarawak. This is to ensure the availability of proper infrastructure for children at school and to create a conducive learning environment.

Steps will also be taken to improve the academic achievements of students, especially rural students. The improvement of teaching quality and the learning environment in rural schools including providing ICT facilities will be emphasised under the Plan which focused on to produce qualified and skilled teachers. The Government has allocated RM690 million for teachers' accommodation or housing quarters. Half of this allocation will be for teachers' housing quarters in rural areas. This will indirectly improve the teachers' living condition in the rural areas.

2.3.2 Electricity for Education

The United Nation Development Programme in the Millennium Development Goals 2 (MDG2 – Achieve Universal Primary) has stated that education in Malaysia had achieved the MDG target in 1990. The target is to ensure that by year 2015, all children everywhere in the country are to complete the primary schooling. However despite the success in achieving universal primary education, challenges remain in improving the quality of the primary education, not only on the curricular aspect but also to improve the schools' infrastructure to make a better learning environment. This is due to the fact that the academic performance of rural area students lags behind as compared to students from urban areas. Two reasons behind this finding are;

a) Lack of experienced and trained teacher. Most teachers try to avoid being posting in the rural areas especially the remote and unelectrify schools. Most of the rural schools will have teachers at a very short term; due to teachers who are being posting in the rural schools will tend to request for transfer to urban area after at least a schools term.

b) Digital divide between rural and urban area due to poor ICT infrastructure. Even though at present all 10,000 schools in Malaysia have internet access (either via satellite or cable connection), schools that do not have electricity will never get access to the service.

Therefore, the biggest motivation to the teachers and also to the students will be to electrify the schools with a more stable, sustainable and reliable power supply, which they can use for 24 hours a day. As how the conventional 24 hours grid connected has influenced and give impact to the lifestyle of human being; an alternative resource from renewable energy may also shows potential – in the technical as well as in the social, economical and financial sense - in the rural areas that have difficulty in accessing to the grid.

In line with the government's aspiration to utilize and develop more renewable energy by 2010 and to ensure that more rural areas will get benefit from the electricity supply program from renewable energy technology, the Ministry of Education (MOE) has initiated the Solar Hybrid System for Rural Schools in Sabah Project. The ministry had indentified 270 rural schools in Sabah that need a sufficient and reliable electrical power supply.

Electricity should be given top priority to the schools as it is very important for education based facilities like computers, communication system, lighting and etc. All these schools are currently and for the next five to ten years will still not be able to be connected by the grid system from the electricity utility company, SESB. Hence, the first phase was implemented in 2008 and the aimed was to give alternative electricity solution to 78 rural schools in Sabah using Solar Hybrid System.

3 SOLAR HYBRID SYSTEM FOR RURAL SCHOOLS IN SABAH

3.1 Overview

In line with the government's aspiration to utilize and develop more renewable energy by 2010 and to ensure that more rural areas will get benefit from the electricity supply program from renewable energy technology, the Ministry of Education (MOE) has initiated the Solar Hybrid System for Rural Schools in Sabah Project. The ministry had indentified 270 rural schools in Sabah that needs a sufficient and reliable electrical power supply.

The ministry had appointed the Public Works Department of Malaysia to be the project manager and consultant for the project. The department is a well known technical and consultant agency for the government in implementing government projects including Renewable Energy sector.

3.2 Sites Condition Before Implementation of the System

In general, before the implementation of the solar hybrid system, each school used to have a single phase diesel generator that electrifies the entire school. These generators normally operate during the school hour from 7:00 am to 12:00 pm and some also electrifies the teachers' quarters at night from 6:30 pm to 10:00 pm every day. However, problem arises due to reliability of the generator. As all the sites are located remotely, the diesel supply access is very difficult due to cost and logistics issues. Even though the diesel was supplied by the District Education Department every month, the amount of the diesel was too little to meet the school energy demand (approximately four drums per month), which most of the schools have to minimise the electricity consumption. The diesel generators are often operated in the inefficient load range and when they are switched off, no electricity is available at all.

Due to the instability of the power generated from the generator, lot of electronic devices like computers, projectors, photocopy machines were damaged. This creates lot of problems to the schools especially the teacher and the students as they could not used the equipments during the class session. The Malaysian education system nowadays requires the teachers to give lecture interactively using computer and other information and communication technology (ICT) equipments. In addition most of the schools have internet connection using Very Small Aperture Terminal (VSAT) system for the teachers and student to get access to the internet. If there were no alternative to replace the diesel generator, it will create a bigger education gap between the rural area students and the urban students as they are unable to fully utilise the usage of the education tools.

Another problem is the difficulty to maintain the diesel generator. There are no dedicated chargeman should the generator need to be repaired or serviced. Hence, the teachers themselves need to take the responsibility to maintain the generator. The situation becomes worse due to the limited lifetime of the combustion motors, low load efficiency, the noise created by the generator and the exhaust gasses which makes it undesirable to have a continuous operation of the diesel generator.

3.3 Solar Hybrid System

The solar hybrid system will integrate two or more power sources. It is a more reliable system as compared to stand alone solar PV system for the multiple power sources that connected together. The system which has been installed at 78 sites, combines PV array with diesel generator and operates with solar inverter. This can help to conserve energy by reducing the use of diesel fuel from generator and maximize the system efficiency.

The solar hybrid system for the rural schools in Sabah was designed to supply electricity for every load in the school. School buildings like class room, computer lab, guard house and teacher's quarters were connected to the solar hybrid grid system.

3.3.1 List of Sites and Site Samples

A total of 78 rural schools in Sabah have been installed with Solar Hybrid System. The schools were selected from a total of 270 schools in Sabah that do not have electricity connected to the grid. The other schools which are not listed in the first phase are expected to get the system in the next phase, as this project is a continuous program for rural area development.

In summary, the schools can be categorized into four packages; with the first package has 66 schools and the other packages have four schools each. The schools are located in fifteen different districts and are spread all over the state. Hence, the geographical condition of the schools' area may differ among others. The location of the sites is shown in figure 2.3 below.

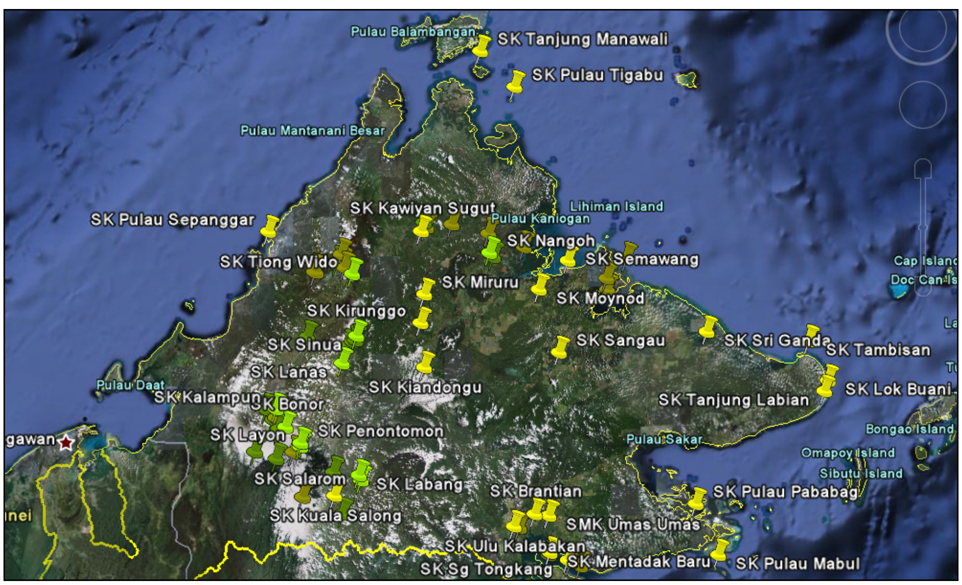


Figure 3.1 : The rural schools' location in Sabah. (Source : [11]).

Depending on the energy demand of the schools, the sizing of the solar hybrid system also differs from each school. Table 2.1 below shows the number of schools with PV system sizing. The detail schools and system explanation can be found in Table 9.2 in the appendix.

Table 3.1 : Total schools with PV system sizing

Package No	PV Sizing System	Total Schools
1	10	14
	15	25
	20	15
	25	3
	30	6
	40	2
	50	1
2	15	2
	25	2
3	20	4
4	28	2
	22.75	1
	40	1
Grand Total		**78**

For the purpose of the analysis study for this master thesis, two schools have been identified to be the sample sites for evaluation and analysis processes. The list of the selected schools is shown in Table 3.2 below.

Table 3.2 : List of schools which are used as samples for the analysis and evaluation processes.

No	School Code	School Name	District	Package No	Coordinate	PV System Sizing	System Type
1	XBA1105	SK[2] Penontomon	Keningau	1	N 4°52.73' E 116°15.9'	20 kW	DC Coupling
2	XBA4041	SK Pulau Sepanggar	Kota Kinabalu	2	N 6° 4.068' E 116° 4.723'	25 kW	DC Coupling

[2] SK is Sekolah Kebangsaan in Malay, in English is Primary School

3.2 Load Profile

In general, each school consists of class rooms, computer lab, office, pre-school, canteen and teachers' quarters. Table below lists the number of school buildings/rooms for both schools.

Table 3.3: Lists of schools buildings/rooms for both schools.

Buildings/Rooms	SK Penontomon	SK Pulau Spanggar
Class room & pre-school	7	9
Computer Lab	1	1
Office	1	1
Canteen	1	1
Teachers' quarters	6	3

Note : A teacher's quarters normally occupied by a family or two to three single teachers. For SK Penontomon only the school's principle lives with family.

3.2.1 Description of Loads and Load Profile

3.2.1.1 SK Penontomon

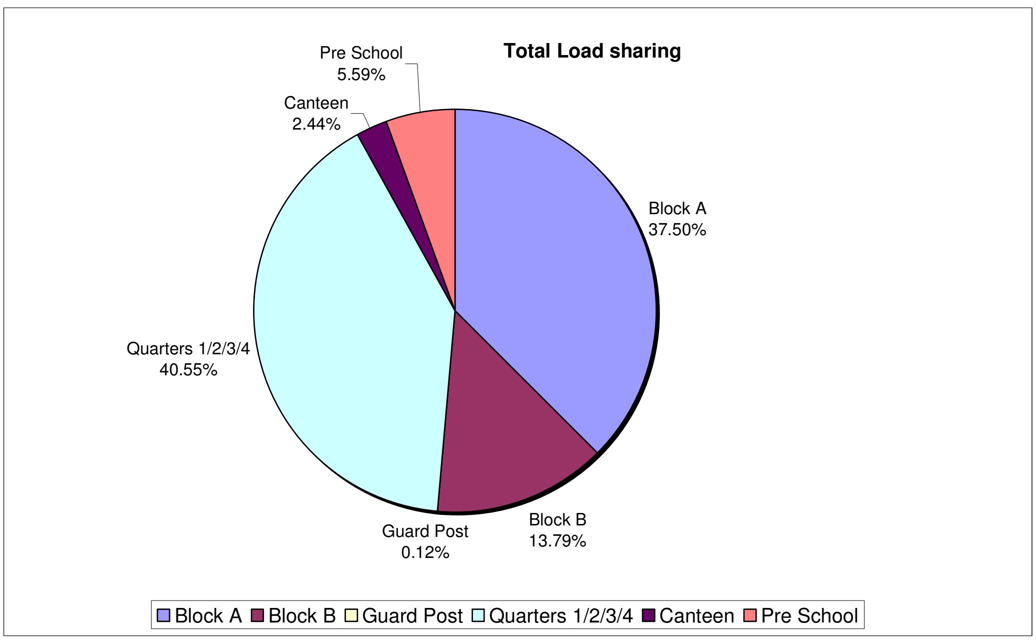


Figure 3.2: Distribution of loads in each school building. Block A consists of class rooms, teacher's office and computer room, while Block B consists of class rooms only.

As shown in figure 2.5, the load demand for the school mostly come from teachers' quarters (41.55%), Block A and Block B at 37.5% and 13.79% respectively. And for the future extension, a 20% load extension has been considered in the load analysis.

The total installed rated load power for SK Penontomon is 15.23 kW as shown in the table 2.4 below. The load usage has been distributed over 24 hours load profile which can be used to identify the maximum peak load during the day.

Table 3.4 : List of loads and its power demand at SK Penontomon.

Type	Quantity	Rated Power (W)	TOTAL POWER (W)
Lamp	85	36	3,060
	5	18	90
Fan	35	100	3,500
PC	20	100	2,000
Projector	6	250	1,500
Electrical equipment	10	100	1,000
Refrigerator	4	40	160
Iron	4	300	1,200
TV	4	80	320
Cooker	4	600	2,400
TCL (W)			**15,230**

Note : The rated power for each loads are based on assumption during the design processes. The client has set a maximum allowable system PV sizing for the school must be at 20 kWp.

Fan contributes the highest power demand with 3,500 W from the total load demand. There is no specific load that contributes to seasonal usage, hence the daily load profile is assumed to be the same for everyday in a year except during school holiday and weekend.

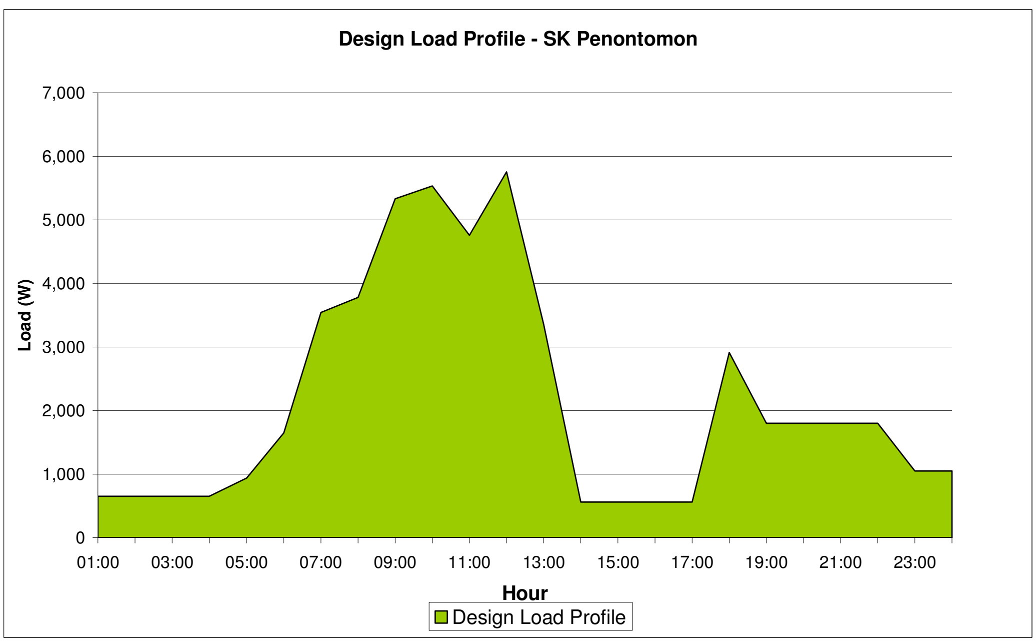


Figure 3.3 : Daily load profile for SK Penontomon.

The peak load is at 5,760 W at noon and the profile has a base load at 560 W.

3.2.1.2 SK Pulau Sepanggar

As shown in figure 3.4, the load demand for the school mostly come from the academic blocks (Block A, B and C) and the main building which contributes 68% of the total load. And for the future extension, a 20% load extension has been considered in the load analysis.

The total installed rated load power for SK Penontomon is 20.37kW as shown in the table 3.5 below. The load usage has been distributed over 24 hours load profile which can be used to identify the maximum peak load during the day.

The peak load is at 9,450 W at 9:00 a.m and the profile has a base load at 776 W.

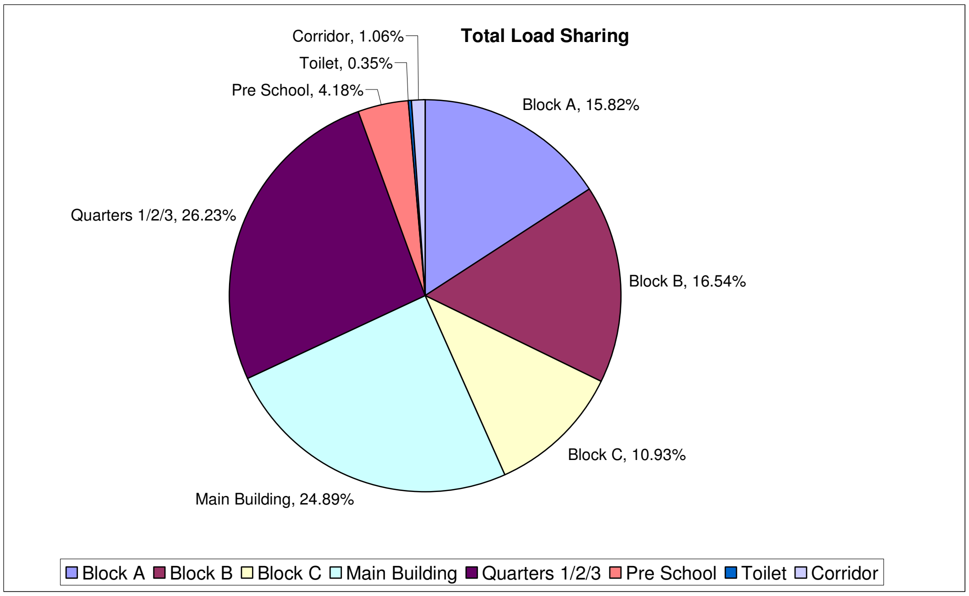


Figure 3.4 : Distribution of loads in each school buildings. The main building consists of Teachers' office and computer room and the academic blocks are Block A, B and C.

Table 3.5 : List of loads and its power demand at SK Pulau Sepanggar

Type	Quantity	Rated Power (W)	TOTAL POWER (W)
Lamp	114	36	4,104
	16	18	288
Fan	53	100	5,300
PC	30	100	3,000
Projector	10	250	2,500
Printer	1	50	50
Electrical equipment	9	100	900
Refrigerator	4	40	160
Iron	4	300	1,200
TV	4	80	320
	1	150	150
Cooker	4	600	2,400
TCL (W)			**20,372**

Note : The rated power for each loads are based on assumption during the design processes. The client has set a maximum allowable system PV sizing for the school must be at 25 kWp.

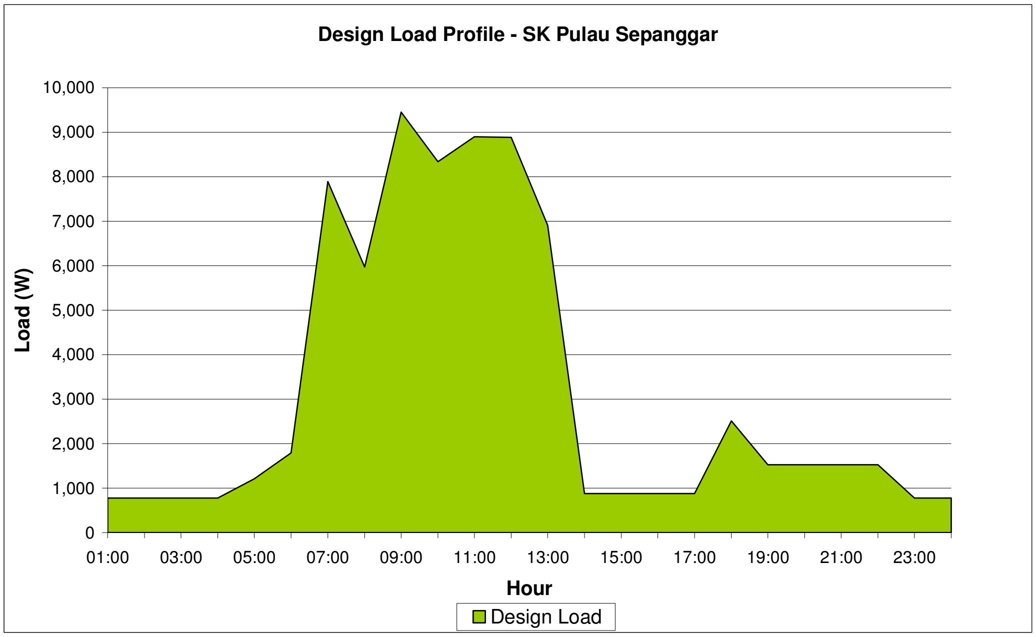


Figure 3.5 : Daily load profile for SK Pulau Sepanggar.

3.2.2 Annual Energy Consumption

The daily energy consumption for SK Penontomon was calculated from the load profile. During daytime the energy demand is at 35,964 Wh which is 69.53% of the total daily energy demand at 51,722 Wh. While night time requires 30.47% of the daily energy demand at 15,722 Wh. Daytime is considered from 06.00 hours to 18.00 hours which is the normal sun rise and sunset for the location.

While for SK Pulau Sepanggar, the energy demand during daytime is at 61,642 Wh (80.97%) and energy demand at night time is expected to consume at 14,488 Wh.

The 365 days of a year were allocated to this profile and the total Annual Energy Consumption (AEC) was estimated. In order to get an accurate AEC, all the possible holidays and weekends have been considered in the calculation. The total days of school holidays and public holidays are considered at 104 days annually while the total weekend (Saturday and Sunday) in a year is 96 days, ie. 8 days a month times 12 months a year. During these holidays and weekends, all loads that are used during the school period especially in academic blocks is considered to be switched off from 07.00 hours to 13.00 hours. Hence the daily energy demand during school holidays and weekends will be at 25,454 Wh for SK Penontomon and 25,928 Wh for SK Pulau Sepanggar.

Table 3.6 : Annual energy consumption at SK Penontomon.

Description	Daily Energy Demand (Wh)	Days	Total Energy Demand (Wh)
School day	51,722.00	165	8,534,130
School holiday/weekend	25,454.00	200	5,090,800
Annual energy consumption (Wh/y)			**13,624,930**

Table 3.7 : Annual energy consumption at SK Pulau Sepanggar

Description	Daily Energy Demand (Wh)	Days	Total Energy Demand (Wh)
School day	76,130.00	165	12,561,450
School holiday/weekend	25,928.00	200	5,185,600
Annual energy consumption (Wh/y)			**17,747,050**

As shown in table 3.6 and 3.7 the annual energy consumption (AEC) for SK Penontomon is expected at 13.6 MWh and 17.7 MWh for SK Pulau Sepanggar

3.2.3 System Configurations

The Solar Hybrid System configurations for both schools are shown in the following Figure 3.6. The PV array is used to supply power to the load and to charge the battery during day time. Priority will be given to satisfy the day time load. The tubular vented deep cycle lead acid battery bank use for storage and supply power to the load during night time. The bidirectional inverter will convert the DC-AC voltage and vice versa. If there were insufficient power from the PV or the battery, the diesel generator set will turned on automatically to supply power to the load. Moreover, any excess electricity from the generator will be used to charge the battery as well. The generator is configured to be automatically turned on one hour every week for warm up and also once every month for several hours for battery equalization.

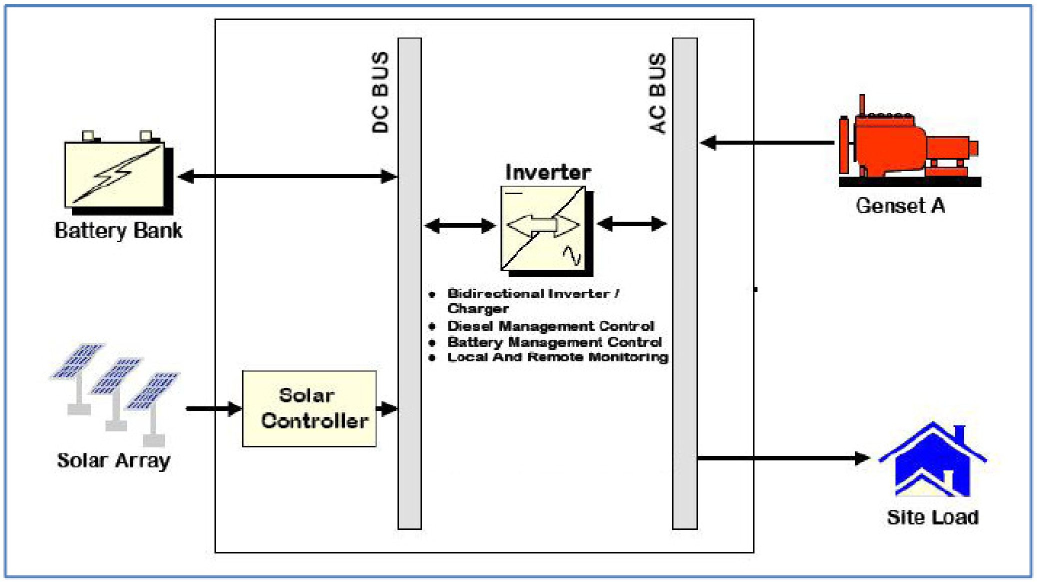


Figure 3.6 : The solar hybrid system configuration diagram. (Source : [16])

Figure 3.7 : Solar PV panel. (Left) 20 kWp at SK Penontomon, (right) 25 kWp PV and 40 kW diesel generator at SK Pulau Sepanggar. (Source : Abdul Muhaimin Mahmud)

Figure 3.8 : 21.6 kW diesel generator at SK Penontomon (Source : Abdul Muhaimin Mahmud)

Figure 3.9 : 3500 Ah battery bank at SK Penontomon (left) and inverter (right) at SK Penontomon. (Source : Abdul Muhaimin Mahmud)

4 MEASUREMENTS AND SIMULATION TOOLS

4.1 Remote Monitoring System – JKR Supervisory Control and Data Acquisition System (jSCADA)

The real time and online monitoring of critical assets such as electricity power supply has become a necessity for any organisations or premises to ensure the service provided is reliable with less interruption on the service.

The system called JKR[3] Supervisory Control and Data Acquisition System (jSCADA) is developed by JKR itself (inhouse) using open structure CPU based hardware and the central application is belong to the Government which can be used without limit and no license is required. This system is first used for the Solar Hybrid System for the rural school project in phase 1.

The system will act as an early warning where any problems on the equipments/components of the solar hybrid system can be channelled directly to the Centralised Online Helpdesk within a short period of time (in seconds or a few minutes) for action to be taken by the responsible person/personnel. This can prevent the problem that will affect the school operation and eventually decrease the repair cost.

The system is developed due to the fact that the operation and maintenance cost can reach € 2,000.00 for maintenance (preventive or corrective) that need to be carried out. The amount is the average cost considering that the site can be accessed by land transportation. However for the sites that need to use water transportation (sea and river) or by air, the amount stated will only enough to cover the transportation cost. Hence, any problem or system breakdown at site can be reported instantaneously to the monitoring system and a preliminary investigation can be conducted remotely. Moreover, the maintenance contractor can identify the real problem and plan the solution before going to the site, which indirectly can save the time taken to fix the problem.

The availability of the internet at every schools using cables or satellite connectivity, VSAT (Very Small Aperture Terminal), helps to ease the process of the jSCADA system. However,all the 78 schools use satellite connection for they can not be reached by cable. The system communication architecture is shown as figure 4.1 below.

[3] JKR is Jabatan Kerja Raya. In English is Public Works Department (PWD)

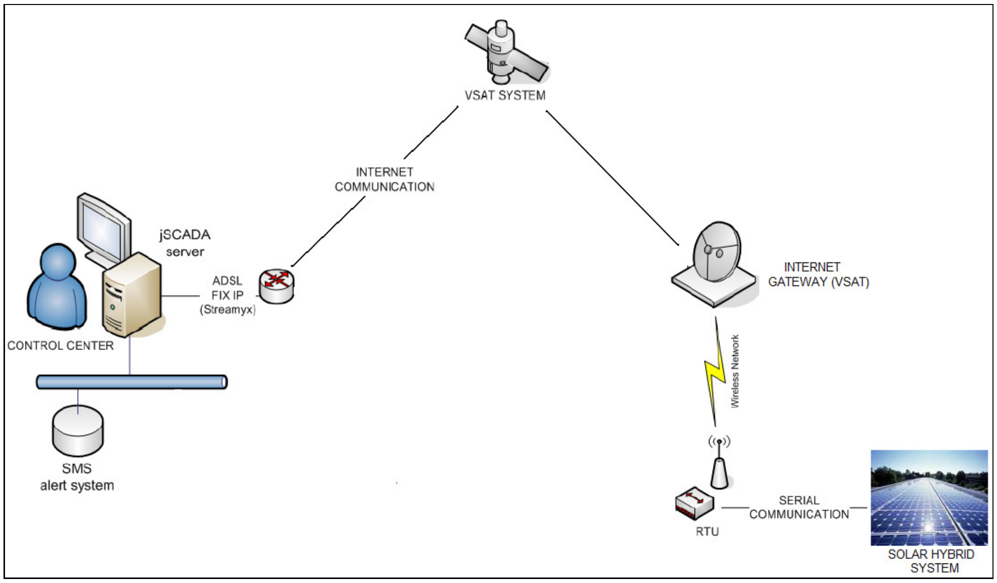


Figure 4.1 : The jSCADA system communication architecture. (Source : [16])

4.1.1 System Description

The system is divided into two main modules;

a) jSCADA Server
b) jSCADA Remote Terminal Unit (RTU)

The jSCADA Server acts as the central data operation and operation monitoring status. It will analyse all data to identify any warning status reported to the system. The main components of the server are database, user interface, supervisor module, warning management system and reporting system.

While the RTU as shown in figure 4.2 below is a device installed at every schools. It has the availability to capture all data measurement required for the system whether using sensors or input/output terminal. The RTU will record and send the data to the Server using the available internet connection.

Among the parameters that are captured include the power produce from the PV panel and the diesel generator, charge and discharge current of the battery, voltages (DC and AC) of PV panel, battery, load and diesel generator, and load consumption.

In the future more important parameters will be added to the jSCADA system like irradiation, PV panel temperature and wind speed. Moreover, it has been planned that the system can also run the control purposes. But this is still under consideration.

At present the system's interface is only available in Malay language. English language will be added in the near future.

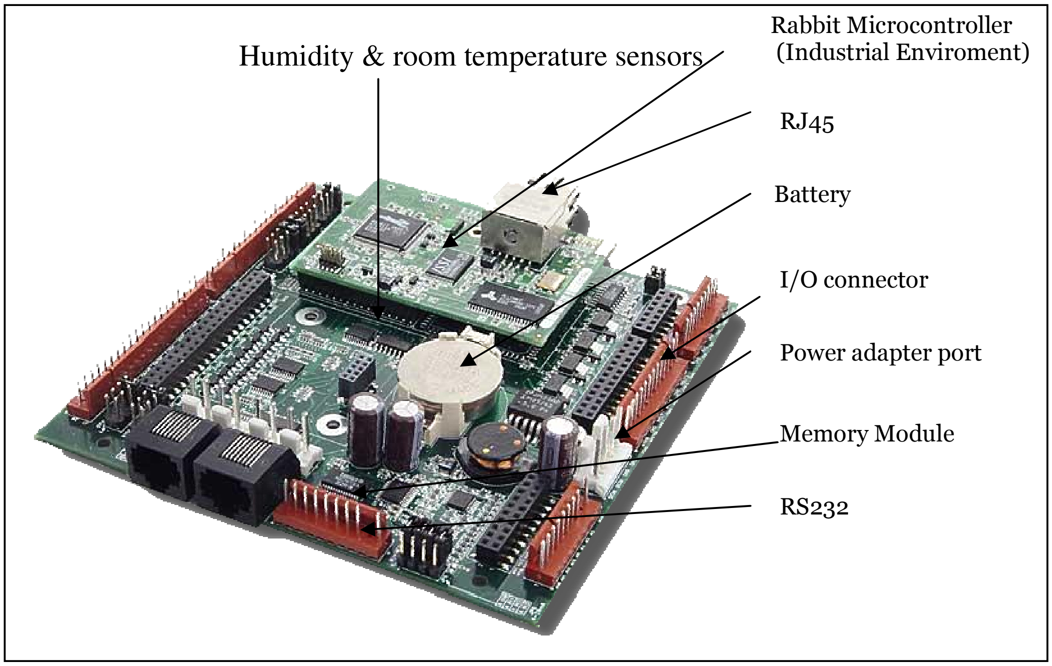


Figure 4.2 : jSCADA remote terminal unit (RTU). (Source : [16])

Figure 4.3 : From left; the contractor's interface, the supervisor's interface and the user's interface. (Source : [16])

4.1.2 System's Barrier

The main barrier in implementing the system is the connectivity from the site to the server. All the 78 schools use VSAT connection for internet access. The VSAT connection is supplied and belongs to other organisation and the JKR has no authority to control the VSAT system should the VSAT system breakdown. In this case, the jSCADA system is only share the connectivity. The performance of the connection is very unpredictable due to several reasons;

a) Modem breakdown. All the VSAT systems were installed several years before the Solar Hybrid System. Hence all the modems now are aging and have the potential to breakdown. This is due to the schools use diesel generator and the modems are very sensitive to unstable power source.

b) The alignment of the outdoor unit (satellite disc) may not correct which result in bad communication that may happened especially during bad weather.

c) The network itself is being shared by other 10,000 school all over Malaysia. The accessibility is based on best effort basis which may affect the process of the daily data transfer to the server.

The implication of the reasons describe above may result in bad or sometime lost in communication connection. Hence, if this situation happened the recorded data will not be transferred to the jSCADA server. Discussion and planning are still in progress between the JKR, the clients and the owner of the communication network to ensure that the availability of the jSCADA system can be achieved 100%.

4.2 Simulation

Homer simulation was used to give comparison between the simulation results and the actual data measurement. The results also will be used to analyse the financial and economical of the installed system as compared to the conventional diesel generator.

4.2.1 HOMER Simulation Setup

The installed system as explained in the previous chapter is presented in figure 4.4. The input parameters and characteristics of each component are similar to the actual specification of the installed system.

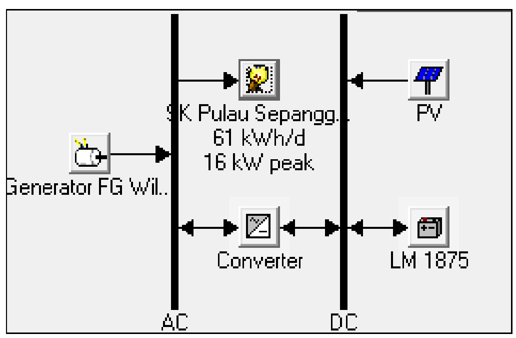


Figure 4.4 : The system setup at SK Pulau Sepanggar. The same setup but with different rated capacity is also used for SK Penontomon (Source : [9]).

The daily average irradiance of both locations is almost the same at 5.09 kWh/m2/day, as shown in figure 4.5. From the figure, the variation of the irradiation over the year is small and the locations are located in the moderately feasible belt for solar application which indicates that both locations are rich of solar energy over the year. However, the irradiation data is referred to the 2005 recorded data, which might not be 100% accurate as compared to the actual irradiation in the measurement year. This is due to the sites do not have tools to record irradiation like pyranometer or solarimeter.

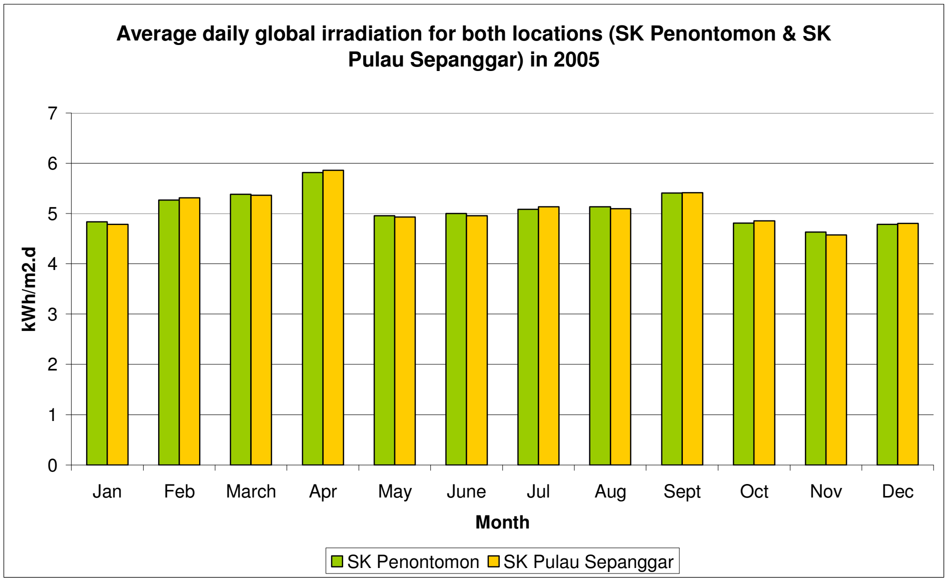


Figure 4.5 : The average daily global irradiation for both location at SK Penontomon and SK Pulau Sepanggar (Source : [8]).

5 RESULTS AND ANALYSIS

5.1 Impact on the Solar Hybrid System

Two sites were selected which are SK Penontomon in the district of Keningau and SK Pulau Sepanggar in the district of Kota Kinabalu. SK Ponontomon is located 50 kilometres from the main road and Keningau town. SK Pulau Sepanggar is an island and is located 25 kilometres to the north of the main city Kota Kinabalu. The island can be reached by water transport from the nearest jetty which is Sepanggar Bay. The jetty is located five kilometres from the island.

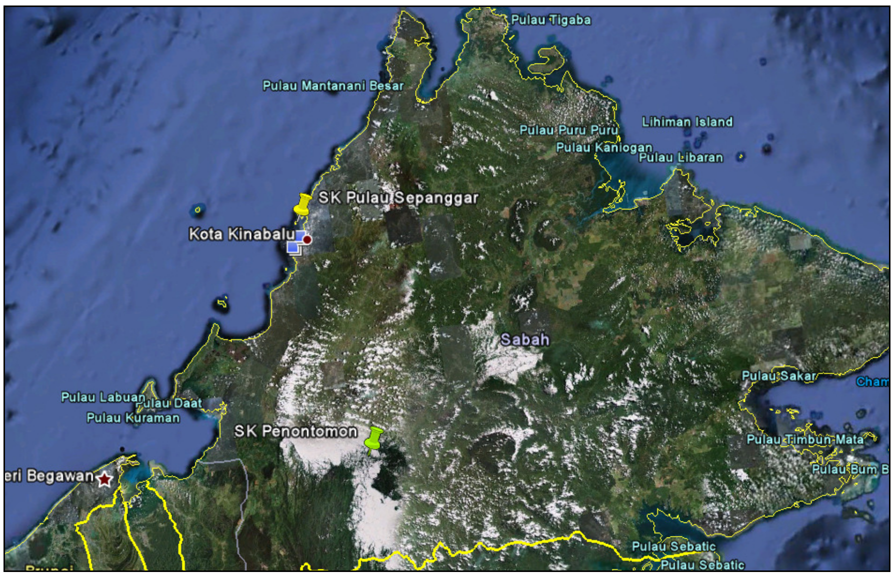


Figure 5.1 : Location of SK Penontomon and SK Pulau Sepanggar. (Source : [11])

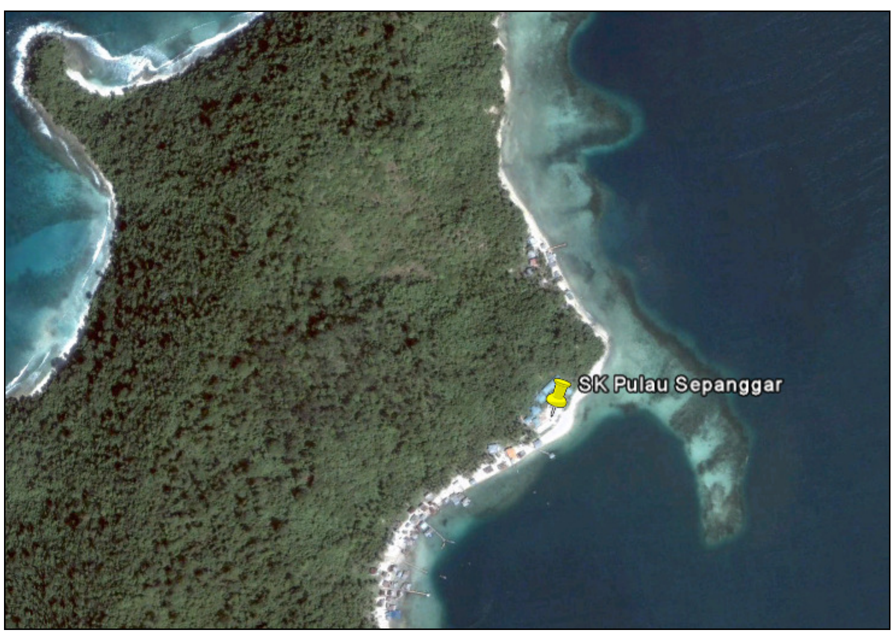


Figure 5.2 : Pulau Sepanggar and the location of the school. (Source : [11])

Forty respondents were chose from both schools, which consist of twenty teachers and twenty students. The table below lists the summary of the respondents.

Table 5.1 : Respondents from selected schools

SCHOOL	TEACHER	STUDENT
SK Penontomon	6	10
SK Pulau Sepanggar	14	10

All the six teachers from SK Penontomon live in the teachers' quarters inside the school area, while only six SK Pulau Sepanggar's teacher lives in the teachers' quarters. Most of the teachers at SK Pulau Sepanggar live in nearby town or village. While all the school students live in the village of Penontomon and Pulau Sepanggar. Figure below shows the schools' main building.

Figure 5.3 : SK Penontomon main building (left) and SK Pulau Sepanggar main building (right). (Source : Abdul Muhaimin Mahmud)

In general, each school consists of class rooms, computer lab, office, pre-school, canteen and teachers' quarters. Table below lists the number of school buildings/rooms for both schools.

Table 5.2 : Lists of schools buildings/rooms for both schools

Buildings/Rooms	SK Penontomon	SK Pulau Sepanggar
Class room	4	9
Computer Lab	1	1
Office	1	1
Canteen	1	1
Teachers' quarters	6	3

Note : A teacher's quarters normally occupied by a family or two to three single teachers. For SK Ponontomon only the school's principle lives with family.

5.1.1 Knowledge

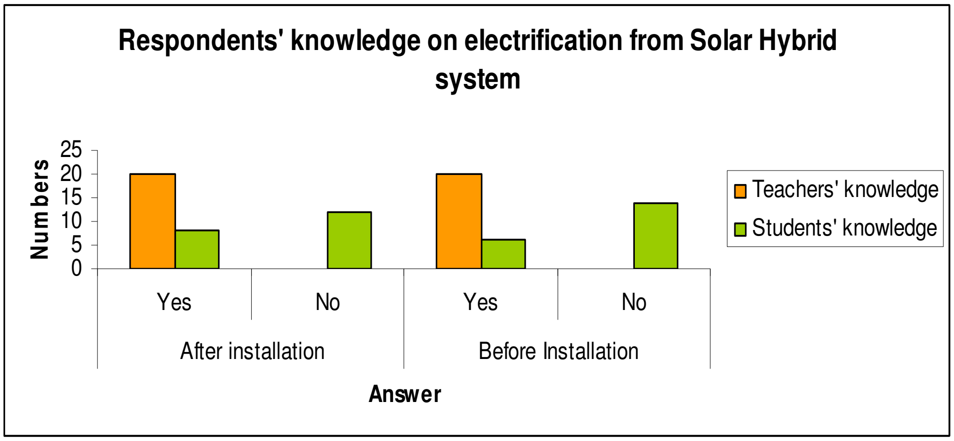


Figure 5.4 : Respondents' knowledge on electrification from solar hybrid technology system.

All the teachers have some knowledge of the Solar Hybrid System before the installation of the system, but only six students knows about the system before the installation of the system. The numbers of the student that gain information of the system after it is in operation increase by 10%.

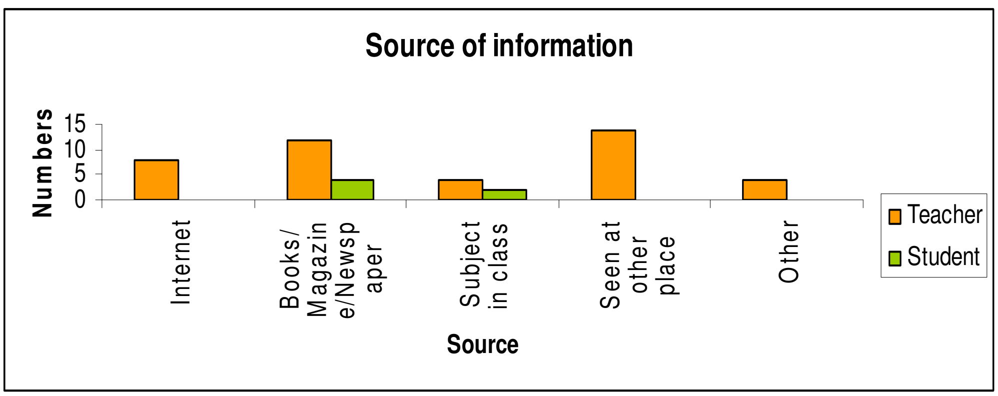


Figure 5.5 : Lists of sources on how or where the respondents get the information of solar system technology to produce electricity.

Books, magazines and newspapers are the most popular sources of information of the system. 40% of the respondents have read about the technology. For the students, most of them know about renewable energy by reading from the school library. Alternative information is from the internet where 20% of the respondents get the information from the World Wide Web (www.). The access of the internet can be found from the schools computer lab or at other places/towns nearby.

35% of the respondents have seen the technology before at other places/villages. The technology were installed for village communities on several rural electrification programmes like Solar Home System (SHS) by Ministry of Rural and Region Development and Solar PV System for Rural ICT Centre by Ministry of Energy, Green Technology and Water.

The education system also provides some basic information of renewable energy system in standard six's Science subjects. 16% of the respondents learn/teach the subject and mostly they are the Science teachers and standard six students.

Four respondents reply that they get the information from other sources. Three of them by informal conversation and the other one have a stand alone PV system installed at his house nearby.

5.1.2 Condition Before Installation

Both schools used diesel generator to provide the electricity needed by the school loads. The size of the generators is 5 kW and had been used for almost more than five years. The normal operation of the generator would be from 7:00 a.m to 12:00 p.m which is during the school session. If the diesel supply is enough, it would also be in operation from 6:30 p.m to 10:00 pm, which most of the supply would be used to meet the teachers' quarters' energy demand at night.

However, as the diesel generators are used directly to supply the consumer load, the generators are often operated in the inefficient load range and when they are switched off, no electricity are available at all. Due to the instability of the power generated from the generator, a lot of electronic devices like computers, projectors, photocopy machines were damaged. This creates a lot of problems to the schools especially the teacher and the students as they could not used the equipments during the class session.

Another problem is the difficulty to maintain the diesel generator. There is no dedicated person to look after the generator should the generator need to be repaired or serviced. Hence, the teachers themselves need to take the responsibility to maintain the generator. The situation becomes worse due to the limited lifetime of the combustion motors, low load efficiency, the noise created by the generator and the exhaust gasses which makes it undesirable to have a continuous operation of the diesel generator.

As all the sites are located very remotely, the access to have diesel supply is very difficult due to logistics and pricing issues. Even though the diesel was supplied by the District Education Department every month, the amount of the diesel was too little to meet the school energy demand (approximately four drums per month).

By calculation, to determine the numbers of days that the old diesel genset can meet the users' load demand per month is given as follows;

1 drums of diesel	=	*1 barrel of diesel*
	=	*158.98 litres*
Total monthly supply	=	*4 drums X 158.98 litres*
	=	*635.92 litres of diesel per month*

Assumptions;

a) Assume that the diesel genset runs on average of 8 hours a day, ie, four hours during school period and four hours at night,

b) The genset runs at 75% of load with fuel consumption at 3.5 litre/hours at 50 Hz frequency, and
c) The old genset is in good condition and no breakdown occurred.

Hence, the total hours the genset in operation with the monthly supply diesel is;

$$\text{Hours operation} = \frac{635.92 \text{ litre}}{3.5 \text{ litre/hour}}$$

$$= 181.69 \text{ hours}$$

$$\text{Days operation} = \frac{181.69 \text{ hours}}{8 \text{ hours/day}}$$

$$= \underline{\mathbf{22.7\ days}}$$

Therefore the number of days in one month that the genset can supply electricity to the end users is at most 23 days a month.

5.1.3 Condition After Installation

The solar hybrid system at SK Penontomon started operation in May 2009 while SK Pulau Sepanggar was electrified by the system in March 2009.

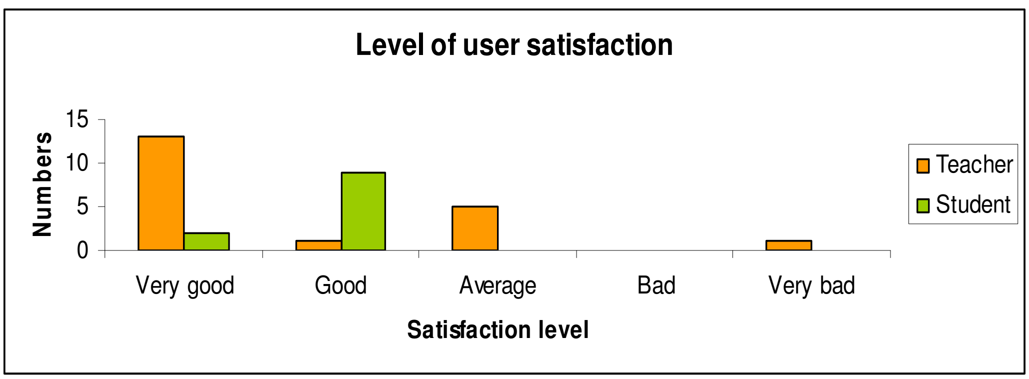


Figure 5.6 : Level of user satisfaction when experiencing the use of the solar hybrid system.

Note : Very good – the system has not experienced any power shortage.
Good – the system had experienced power shortages at least five times from its first day of operation.
Average – the system had experienced power shortages at least once a month.
Bad – the system had experienced power shortages at least once a week.
Very bad – the system had experienced power shortage every day.

The respondents were asked to give their opinion on how would they rate the system base on their daily electricity usage. All respondents from SK Pulau Sepanggar rated the system as very good or good. This is due to the system always give enough power to the load and the trip off occurrences can be negligible.

However, six respondents in SK Penontomon, rated the system as average (five) and very bad (one). The system always trip off during the early morning between 0100 hours to 0700 hours and this situation only occurred at two teachers quarters. The system would resume automatically when the sunshine came. There might be several reasons given by the respondents which are:

1.) The system could not meet the energy demand due to additional electrical equipments installed after the system in operation. It was found out that most of the quarters' resident started buying electrical appliances like refrigerator (some of them use refrigerator to sell ice cream and ice cube), television (one house has a 29' CRT TV) and satellite modem for TV channel.
2.) A user installed illegal electrical wiring to connect house which is in 30 metre range from the school building.

After detailed investigation with the project team and contractor, besides the increasing number of electrical appliances and the illegal electrical wiring, one of the inverter (there are three inverters in total with one act as master) was malfunction and not configured correctly. The inverter did not synchronize with the master inverter which resulted when the inverter trip off, the master inverter did not sense the condition and hence could not send signal to the generator to start.

There are two level of protection at site which are the battery low voltage level and power limiter. Power limiter was installed at each teacher's quarters to ensure that they will not overuse the energy from the battery especially during night time. Which ever comes first will disconnect the supply from the battery to the loads.

5.1.4 User Training

At least a teacher from each school is required to attend training on solar hybrid technology. The teacher which mostly was selected among science teachers will be responsible to give the information on the technology to the other user. It is found that only informal explanation was given to the users. Only 24 respondents were given informal information and eighteen respondents understand well about the technology, while another six respondents requested more explanation and formal training should be given to them.

The main barrier in implementing PV system in any rural electrification programme is the operation period. PV system and their implementation are frequently looked upon in a very simplistic manner by a number of people which has resulted in a large number of failures [7]. Proper transfer of technology training programme is required for the end user because awareness and knowledge on the system technology are equally as important as the adequate financing and institutional framework.

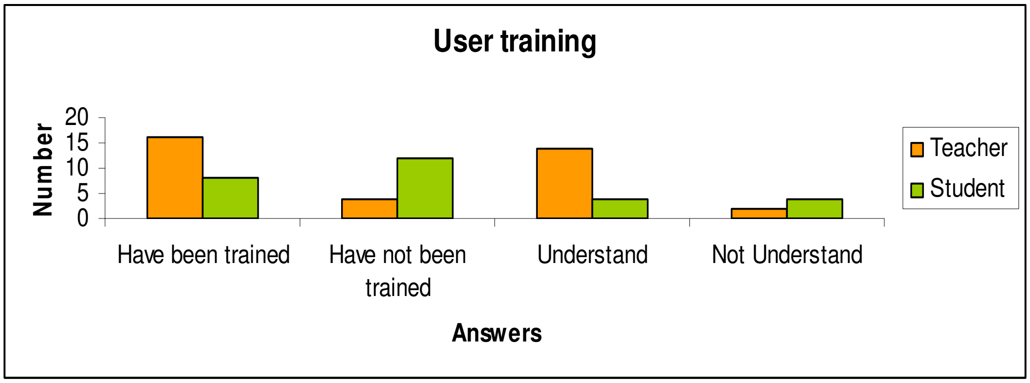


Figure 5.7 : User training

5.1.5 Load Management Strategies

All the respondents replied that they practiced load management when using the electricity. However, they do not have a schedule management or do not strategies their usage. All loads will only be turned on when required. For example, if during the class there was enough sunlight to light the room, lamps will not be used. All the loads in the school building will be turned off when there are no occupants in the room, except for equipments that need 24 hours operation like refrigerator.

5.1.6 Users' Opinion

All the respondents voted that the technology give benefit and impact to their lifestyle and the learning environment. Nowadays, the teaching and learning processes are more comfortable where teachers can use interactive teaching methods using computers and projector at anytime during the school period. Besides, the teachers and students can get access to the internet from the already installed satellite communication system (Very Small Aperture Terminal – VSAT). There are no more cases of damage electronic equipments after the installation and for teachers who live in the teachers' quarters; they can have access to the latest news and entertainment from the television and radio, can store food in the refrigerator, and can stay awake for more time during the night. As for the students, they can have extra classes during the night especially for students who will sit for the national primary school examination.

Even though there were cases of trip off supply as explained in section 4.0 above, the conditions experienced by the respondent is very much improved as compared to the conditions before the installation.

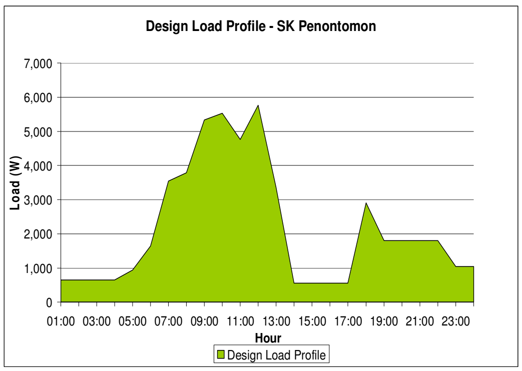
95% of the respondents believe that the nearby village should be connected by any kind of renewable energy technology especially the solar hybrid system. They believe that, electricity is an important element for developing a community and nation and therefore can bridge the development gap between the urban and rural area in economy, education, lifestyle, communication and etc.

5.2 Implementation and operation of the Solar Hybrid System

5.2.1 Design and Actual Load Analysis

This section was done to analyze the differences or similarities of the design load profile with respect to the actual load profile. The design load profile was done before the implementation of the project. Due to limitation of time, during the design stage, no site surveys were conducted in determining the load profile of both sites, but the load profile was created base on the information of the loads given by the clients. Site surveys were only conducted when the systems' design completed.

Figures 5.8 to 5.12 below show the comparison of the load profile for both schools.



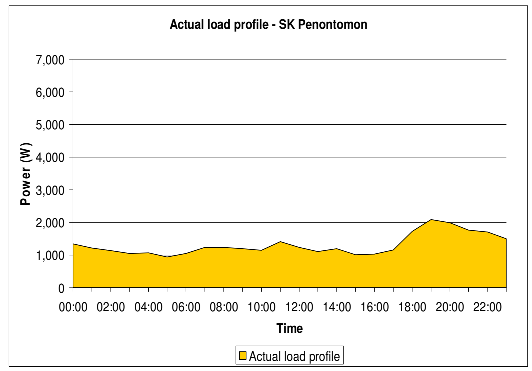
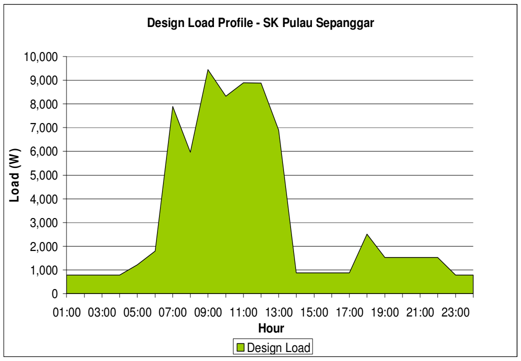


Figure 5.8 and 5.9 : The design load profile (left) and the actual load profile (right) for SK Penontomon. The actual load profile was calculated base on the load consumption in September 2009 recorded from the JSCADA system.



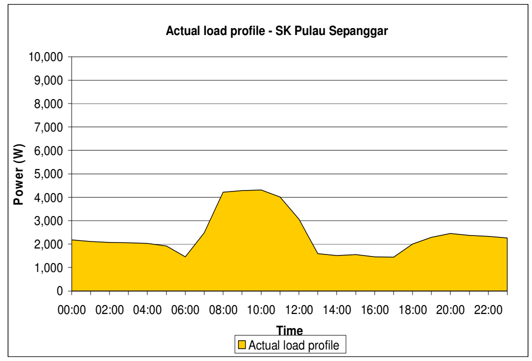


Figure 5.10 and 5.11 : The design load profile (left) and the actual load profile (right) for SK Pulau Sepanggar. The actual load profile was calculated base on the load consumption in July 2009 recorded from the JSCADA system.

The graphs above show that there are differences between the design and the actual load profile. The differences can be shown as the following table;

Table 5.3 : Comparison between the actual and design load profile for both schools.

LOAD	Unit	SK Pulau Sepanggar		SK Penontomon	
		ACTUAL	DESIGN	ACTUAL	DESIGN
Daily Energy consumption	Wh	57,422.57	76,130.00	31,513.63	51,722.00
Max power (load)	W	4,308.02	9,450.00	2,084.13	5,760.00
Min power (load)	W	1,441.46	776.00	935.56	560.00
Day energy consumption	Wh	31,367.63	61,642.00	14,002.59	35,964.00
Night energy consumption	Wh	26,054.95	14,488.00	17,511.04	15,758.00

The actual base load (minimum load) for both schools are double the value of the design base load. The maximum actual load is half the value of the design load. The maximum actual load for SK Penontomon occurred during night time instead of daytime as assumed in the design profile.

The users consumed almost the same amount of energy during day and night time but the total daily energy consumption still less about 30% than the design values. But the users tend to use more energy during night time as compared to the design profile.

The actual energy consumption at SK Penontomon was higher during night time, but users at SK Pulau Sepanggar used more energy during day time. The reason might be that, as explained in Chapter 3, the teachers' quarters in SK Penontomon contribute 41% of the total load sharing, while for SK Pulau Sepanggar, 75% of the school buildings are used during the day time, specifically during the school period.

5.2.2 System Operation Analysis

5.2.2.1 Loss of Load, Solar Fraction and System Performance Ratio

In order to evaluate the energy production and performance of the solar hybrid system, the energy yield and losses of the daily statistics (with hourly values) in tabular form can be generated [4]. The definitions of the *energy yields* and *system losses* can be found as shown in table 6.4 below. As this report is only considering the storage interval of hourly data for one month, the average values for power can be normalized by dividing them with the nominal PV power, genset power and battery power.

Parameter that can determine the reliability of the PV system to supplies electricity to the load is *Loss of Load (LL).* Some literatures define as Deficit Energy, Loss of Power, Unmet Electricity Load etc. Loss of Load is defined as the ratio between energy deficit and the energy demand, both referring to the load, over the total operation time of the installation [7]. The loss of load can also be defined as the percentage of time that the system will not be able to satisfy the load [12]. A recommended value for domestic appliances is 10^{-1} [12]. This study is taking the second definition of loss of load because the measurements are base on time series data. Hence the total time of when the load could not be satisfied by the PV/storage/generator system over the total operating period of the system will the defined the loss of load value.

Moreover, another two useful parameters to relate the reliability of the system are the *Generator Capacity, C_A* and the *Accumulator Capacity, C_S*. C_A, is defined as the ratio of the daily energy output of the PV generator divided by the daily energy consumption of the load. C_S is defined as the maximum energy that can be extracted from the accumulator divided by the daily energy consumption of the load. Hence the equations will be;

$$C_A = \frac{E_{PV}}{L} \qquad \text{and} \qquad C_S = \frac{C_u}{L} \qquad [1]$$

Where E_{PV} is the daily energy output of the PV generator, L is the daily energy consumption of the load and C_u is the maximum energy that can be extracted from the battery. For rural electrification purposes as mentioned in [7], the values of both C_A and C_S are commonly used as $C_A \approx 1.1$ and $3 \leq C_S \leq 5$. But C_A is also depending on the local solar climate condition.

Solar fraction, also known as renewable energy fraction, is defined as the amount of energy provided by the solar technology system divided by the total energy required [13]. This will show the system dependency on the diesel generator as compared to the solar PV and storage system.

The *performance ratio, PR* of the Solar Hybrid System is used as a quality indicator as it will indicates how the energy on the generator (PV, battery and genset) is exploited to meet the energy demand. Theoretically, a good PV system reaches performance ratio of 60% or higher. Performance ratio under this value indicates the system might have malfunctions.

The *battery energy efficiency,* η_{Wh} is the ratio of the energy discharged from the battery to the energy charged to the battery within a certain period of time. In this study one month energy efficiency is calculated.

Table 5.4 : Definitions and descriptions of the energy yields and losses for a PV plant. (Source :[4])

Symbol	**Term**	**Description**	**Unit**
Y_r	Reference Yield	$Y_r = H_I / G_o$. Y_r is equal to the time which the sun has to shine with G_o = 1 kW/m^2 to irradiate the energy H_I onto the solar generator	$\frac{kWh/m^2}{d * 1kW/m^2}$
L_c	Capture Losses	**Thermal capture losses, L_{CT} :** - Losses caused by cell temperature higher than 25^{o}C **Miscellaneous capture losses, L_{CM} :** - Wiring, string diodes, low irradiance - Partial shadowing, contamination, snow covering, inhomogeneous irradiance, mismatch - Maximum power tracking errors, reduction of array power caused by inverter failures or when the accumulator is fully charged (stand alone system) - Errors in irradiance measurements - When irradiance is measured is measured with pyranometer : spectral losses, losses caused by glass reflections	$\frac{kWh}{d * kW_p}$
Y_s	System Yield	$Y_s = E / P_o$. Y_s is equal to the time which the PV hybrid system (PV, genset and battery) has to operate with nominal PV hybrid system power, P_o to generate energy, E	$\frac{kWh}{d * kW_p}$
L_s	System Losses	Inverter conversion losses (DC-AC), accumulator storage losses and genset power losses	$\frac{kWh}{d * kW_p}$
Y_f	System Final Yield	$Y_f = E_{use} / P_o$. Y_f is equal to the time which the PV hybrid system has to operate with nominal PV hybrid system power P_o to generate the useful output energy, E_{use}.	$\frac{kWh}{d * kW_p}$
PR	Performance Ratio	$PR = Y_f / Y_s$. PR corresponds to the ratio of the useful energy, E_{use} to the energy which would generated by a lossless, ideal PV hybrid system with solar temperature at 25^{o}C and the same irradiation	%

Note : The reference yield and the capture losses of the PV can not be determine for this study as the actual radiation has not been measured. Hence, the energy yield of the system and how the system performs is analyzed base on the system yield only.

Table 5.5 : Summary of the system energy parameters for both systems

Parameter	Symbol / Component	Unit	SK Penontomon	SK Pulau Sepanggar
Loss of load	LL	%	0	0
PV Generator capacity	C_A	-	1.57	1.50
Accumulator capacity	C_S	-	5.76	3.81
Solar Fraction	SF	%	92%	93%
Performance Ratio	*PR*	%	75%	71%
Energy Efficiency	η_{Wh}	%	94%	108%
System Yield	Y_s	$Wh / W_p . d$	3.77	4.39
System Final Yield	*Yf*	$Wh / W_p . d$	2.82	3.14
System Losses	L_s	$Wh / W_p . d$	0.95	1.29

Both systems satisfy the entire load required. Loss of load value of zero shows that the system which consists of PV, storage and generator is reliable and can produce sufficient and sustainable energy to satisfy the electricity demand by users.

The solar fraction values for both systems show more than 90%; ie, 92% and 93% for SK Penontomon and SK Pulau Sepanggar respectively. The system is dependent on the energy produce from the solar PV and the energy storage from the batteries could meet the demand when there is no or minimum solar irradiation especially during night time. Hence, the dependency on the diesel generator to supply the load is very minimal where it was found out that it is only operated to charge the batteries and maintains the SOC of the battery. Moreover, the configuration to warm up the generator for at least one hour every week works well.

The solar hybrid system at SK Penontomon has lower system losses at 0.95 Wh / W_p . d as compared to the system at SK Pulau Sepanggar. Although the performance ratio of both systems give a satisfactory values; ie, above 70%, the battery energy efficiency of SK Pulau Sepanggar system gives higher discharge energy as compared to the energy charged to the battery during day time.

The condition of the energy of the battery can be explained by the table 5.6, figure 5.12 and figure 8.4 in the Appendix.

Table 5.6 : Summary of the system operation and comparison with the simulation value from HOMER.

Parameter	Symbol / Component	Unit	SK Penontomon		SK Pulau Sepanggar	
			Simulation	Actual	Simulation	Actual
Monthly Energy Production	*PV*	*Wh*	2,862,665.00	1,420,528.85	3,237,944.00	2,334,978.88
	Genset	*Wh*	139,160.80	126,076.67	355,531.00	74,802.55
	Battery (discharge)	*Wh*	487,050.70	698,167.08	517,912.00	765,750.60
Monthly Energy Consumption	*Load*	*Wh*	1,299,323.70	914,083.16	1,878,330.13	1,548,211.87
	Battery (charge)	*Wh*	615,030.30	741,150.31	641,727.10	647,101.89

The system at SK Penontomon satisfied the users' energy demand and consumption. The monthly energy production was greater than the monthly energy consumption. The useful energy was used to electrify the load and also to charge the battery.

The combination of the PV and the generator shows that the system is not very dependent on the usage of the generator and allows a significant lower quantity of diesel used during the measurement. The data also showed that the system works so far without any major problems.

Even though the system at SK Pulau Sepanggar produces enough energy in July 2009, but the main concern would be the over discharge of the battery as can be seen in figure 5.12 below. Almost half of the observation month had been found to have more battery discharging than charging, though the energy produce from the PV panel was high; ie, the power produced varies from 40 kWh/day to 120 kWh/day, but most of the produced power from the PV is used for the day load, since the day energy consumption and night energy consumption are almost the same as explained in section 5.2.1. Besides the higher system loss may also leads to energy that is supposed can be used to charge the battery but is being dumped instead.

The situation lead to the sate of charge (SOC) of the battery to reach as low as 40% SOC, which happened on 22nd July 2009 as shown in figure 5.13 below. Hence the SOC level shows that it is very much dependent on the power production from the PV, and the user daily load consumption, especially during night time.

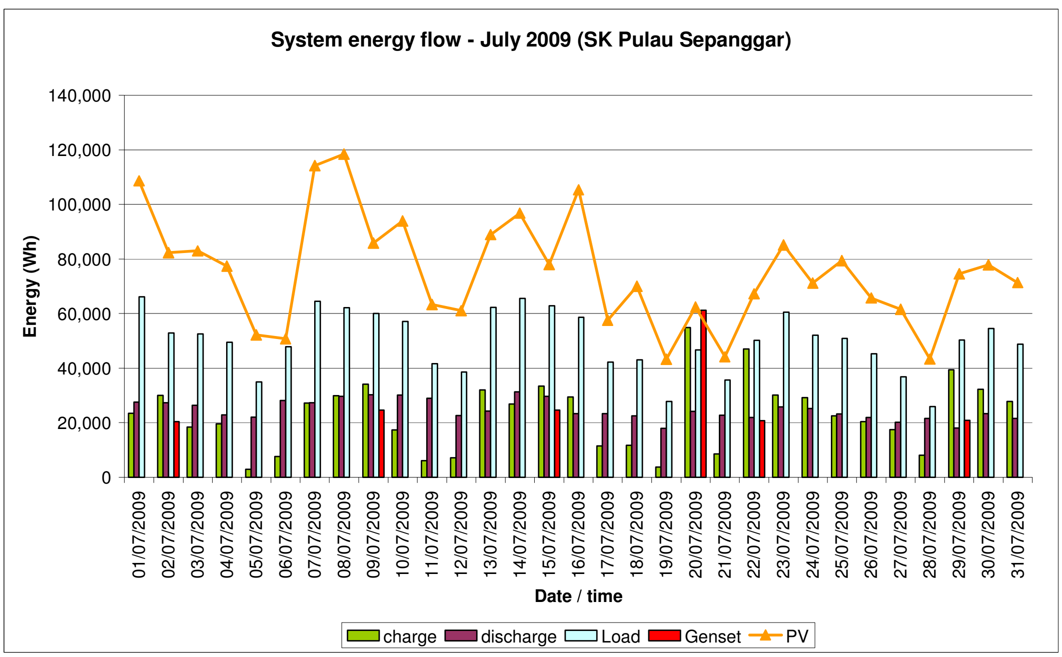


Figure 5.12 : System energy flow of the solar hybrid system at SK Pulau Sepanggar in July 2009.

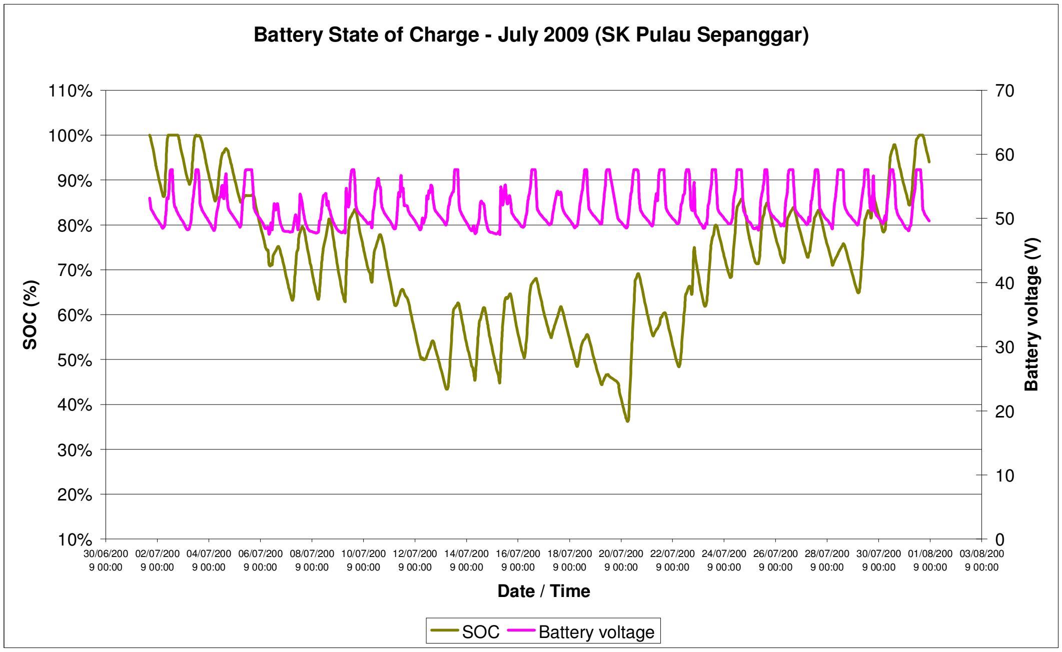


Figure 5.13 : The battery state of charge level at SK Pulau Sepanggar in July 2009.

5.2.3 Economic Analysis

5.2.3.1 Terms and definitions

a) Investment Cost

Investment cost is all the total cost required to install the system at the beginning of the project. This includes the components of the solar hybrid system, the civil works to build the power house and the solar PV panel, electrical works including setting up a mini grid inside the school compound, cost of transportation to deliver all the items and components to the site and labour works.

b) Levelized cost of energy (LCOE)

The levelized cost of energy (COE) is defined as the average cost per kWh of useful electrical energy produced by the system. To calculate the COE, the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) is divided by the total useful electric energy production. The equation for the COE is as follows:

$$COE = \frac{C_{ann,tot} - c_{boiler} E_{thermal}}{E_{prim,AC} + E_{prim,DC} + E_{def} + E_{grid,sales}}$$

where:

$C_{ann,tot}$ = total annualized cost of the system [$/yr]

c_{boiler} = boiler marginal cost [$/kWh]

$E_{thermal}$ = total thermal load served [kWh/yr]

$E_{prim,AC}$ = AC primary load served [kWh/yr]

$E_{prim,DC}$ = DC primary load served [kWh/yr]
E_{def} = deferrable load served [kWh/yr]
$E_{grid,sales}$ = total grid sales [kWh/yr]

The second term in the numerator is the portion of the annualized cost that results from serving the thermal load. In systems that do not serve a thermal load ($E_{thermal}$=0) this term will equal zero.

5.2.3.2 Result

The purposes of the simulation on economic aspect are to analyze and compare the solar hybrid system at both schools with the diesel generator only system. The comparisons include the system investment cost, cost of energy (COE), net present cost, operating cost, annual diesel consumption and the annual cost to buy diesel.

Table 5.7 and 5.8 below shows the result of the simulation. Generally, for either systems (diesel generator only or solar hybrid system), the COE is depending on the sizing of the system. A bigger system capacity reduces the COE. But, it will also increase the investment cost.

The diesel generator system always has better advantage as compared to the solar hybrid system in term of the investment cost and the COE. It is already known that due to fewer components involve in the installation of the diesel generator system, the expenditure on the system is also less as compared to solar hybrid system. The client will only spend 24% out of the total cost to install a solar hybrid system should they opt to use a diesel generator system for both schools. The COE for using diesel generator system is less in between €1.51/kWh - 2.03/kWh as compared to the solar hybrid system for both schools respectively. However as there is no electricity charge impose to the end user, they will not be burden by the higher cost of energy of the hybrid system.

The operating cost of the systems shows that the client will be burden by the higher cost for operating the diesel generator system as compared to the solar hybrid system. Annually, the operating cost for diesel generator system is higher by almost €10,000 when compared to the solar hybrid system. This is due to ensure that the generator is reliable and can give sufficient electricity to the users 24 hours a day, a dedicated person (at least a chargeman) is required to be stationed at both sites. Moreover, the diesel generator has to undergone several services and maintenance processes annually so that it can be always in good condition. This include engine overhaul for at least every 6,000 hours in operation, oil and filter change and decarbonisation. The frequency of services of the generators is higher as compared to the solar hybrid system's generator. All the services and hiring dedicated skill labour will add cost to the operating expenditure.

However, for a solar hybrid system, the service and maintenance routine can be done at least twice a year excluding the corrective maintenance. The generator will have less services every year since the operation hours is minimum. The only concern for the system lies on the batteries system which one can consider as the weakest point of the solar hybrid system. But if a proper maintenance and services schedule applied on the batteries and to the system as a whole, the system can be long lasting with effectively operating cost.

Diesel generator system will consume more diesel because it is the prime energy production for electricity. Hence the client is required to spend more in purchasing the diesel annually. The uncertainties of the global diesel price will directly increase the operating cost of the system. But for the solar hybrid system, most of the diesel operation is mainly to charge and maintains the SOC of the battery which has been explained in section 5.2.2 above. Hence, the operating cost is not dependent on the diesel consumption.

Table 5.7 : Result from Homer simulation on the economic aspect for SK Penontomon.

Parameters	**Symbol**	**Unit**	**SK Penontomon**	
			Genset only	**Solar Hybrid System**
Investment cost	-	€	134,371.00	568,131.00
Cost of Energy	COE	€/kWh	3.83	5.86
Operating cost	-	€/yr	59,787.00	49,415.00
Generator energy produced	-	MWh/yr	29.36	2.06
Diesel consumption	-	L/yr	12,514.00	778.00
Cost of Diesel[4]	-	€/yr	18,771.00	1,167.00

Table 5.8 : Result from Homer simulation on the economic aspect for SK Pulau Sepanggar.

Parameters	**Symbol**	**Unit**	**SK Pulau Sepanggar**	
			Genset only	**Solar Hybrid System**
Investment cost	-	€	164,313.00	617,413.00
Cost of Energy	COE	€/kWh	3.67	5.18
Operating cost	-	€/yr	69,287.00	61,436.00
Generator energy produced	-	MWh/yr	56.57	4.55
Diesel consumption	-	L/yr	24,489.00	1,767.00
Cost of Diesel[5]	-	€/yr	36,733.50	2,650.50

[4, 5] Diesel price is assumed at €1.50 per litre of diesel at both sites. The diesel selling price in Malaysia is at € 0.34/litre due to subsidized by the government. The higher price at both sites compared to the normal selling price is due to logistic cost to supply the diesel to those areas.

Table 5.9 : The cost of each components and per unit costs for SK Penontomon. Price for each components are taken from the project's contract document [17].

Components		**Total Cost** €	**Per unit cost** €/unit	**Comment**
System				
20 kW Solar PV	*201,000.00*		*10.05/Wp*	
3500 Ah Battery system	*206,060.00*		*1.23/Wh*	
21.6 kW Genset	*12,800.00*		*0.59/W*	
19.2 kW Inverter	*21,500.00*		*1.12/W*	
480 A Charge controller	*4,400.00*		*9.17/A*	
Others	*28,400.00*			
Civil		41,823.53		*The works mostly for building the power house to house all the components*
Electrical		52,147.47		*Part of the cost is for building the mini grid in the school compound*
Total Investment Cost		**568,131.00**		
Operation & Maintenance		312,443.00		
Fuel		11,075.00		*The price of the diesel is assumed at €1.50/litre. The price is an average diesel price in the rural area.*
Replacement				*The solar PV has a 25 years lifetime*
Battery	*333,679.00*			*The battery is designed to be replace every 6 years*
Genset	*14,326.00*			*The genset is designed to be replace every 8 years*
Inverter & Charge controller	*23,310.00*			*Inverter and charge controller is designed to be replaced every 15 years*

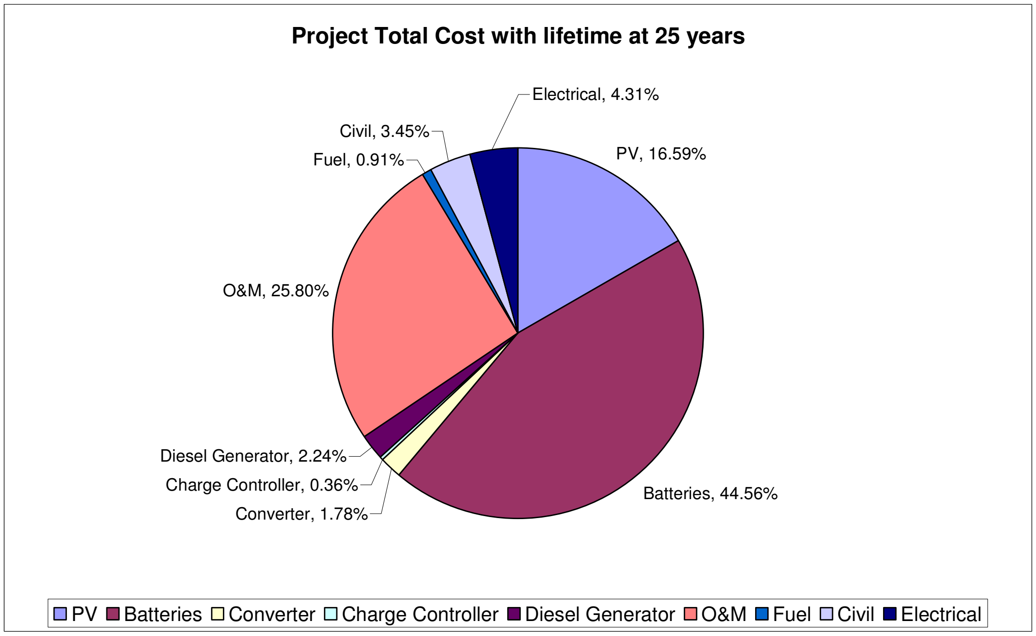


Figure 5.14 : Project total cost of the solar hybrid system. The project lifetime is at 25 years.

Figure 5.14 and table 5.9 above are the total cost of the project in twenty five years of its lifetime. The costs are base on the components cost including their replacement cost, civil works for building the power house, electrical works especially for mini grid installation, fuel costs and the operation and maintenance costs. Replacement of batteries is considered to be every 6 years, diesel generator at 8 years and inverter and charge controller at 15 years. It is clearly shows that the batteries system is the heart of the system where it contributes 45% of the lifetime project cost.

6 CONCLUSION

In this study, the impact of the rural electrification programme using Solar Hybrid System on the learning environment and daily lifestyle of the teachers and students at the rural schools in Sabah, Malaysia has been analysed. In general the solar hybrid system offers better electricity in providing power supply to the rural schools than the old and conventional diesel generator system. The technology gives benefit and impact to the students and the teachers by creating more comfortable lifestyle and conducive learning environment. However, for this study, it is difficult to determine the value of the system with the money that had been invested which can motivate teachers to serve in rural areas especially the skill teachers. This is due to the system is still new and the question can only be answered after the system have been in operation in several years.

The measurements and simulation of the system shows that the solar hybrid system can produce reliable power supply system to meet the rural schools' electricity need. The system was designed and configured correctly but predicting the load pattern to be as accurate as the actual load consumption has always been the challenging part.

The combination of the PV-batteries-generator reduces the dependency of the fuel consumption and fully utilizes the clean energy from the sun. Even though a diesel generator system cost less than a solar hybrid system, but the fact that its operating cost in providing a proper service and maintenance makes the system less favourable as compared to the solar hybrid system. But solving the dependency on the diesel generator does not mean that the reliability and sustainability of the system have been solved. The study shows that the heart of the system lies on the batteries system where it contributes almost half of the total lifetime cost and almost half of the daily consumptions serve by the batteries. Improper conducts on the system like the usage and the maintenance may directly affect the batteries performance which may lead to the failure of the system.

7 RECOMMENDATIONS

The study shows that the implementation and operation of the system in rural area should not be looked in a simplistic manner. Every stages of the implementation show the same important for the successful of the programme. The design stage should put more effort in producing more detail and specific load profile that can reflects the actual load consumption. This can minimize error(s) and mistake(s) and also to prevent any over or under design system which can affect the investment cost of the project. The idea to only assume the load profile without having any site survey should be avoided in the future.

Transfer of technology of the renewable energy technology should be conducted properly. It is a good idea to have at least a trained user for every school to look after the system. However, knowledge sustainability should be address with formal and continuous training to all the users at the rural schools not only for creating awareness and responsibility among them, but for them to share part of the responsibility to take care of the system should the dedicated teacher is transferred out from the school. Take care of the system does not mean that the users have to operate the system, but they should be able to do the first level action at site such as do the reporting to the JSCADA system.

The measurements and results show that the solar hybrid system mostly use the energy produced from the solar radiation to supply the electricity and charge the batteries which makes the system less dependent on the diesel generator. In the future it is recommended that the sizing of the generator shall be smaller with its purpose to charge the batteries only. This will reduce the capital investment and the operating cost of the system.

The Malaysian region receives high solar radiation through the year. Hence the resources must be manipulated by all government, private organisation and individual in promoting renewable energy from solar as a clean power supply not only in rural areas but also every where in Malaysia.

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9 APPENDIX

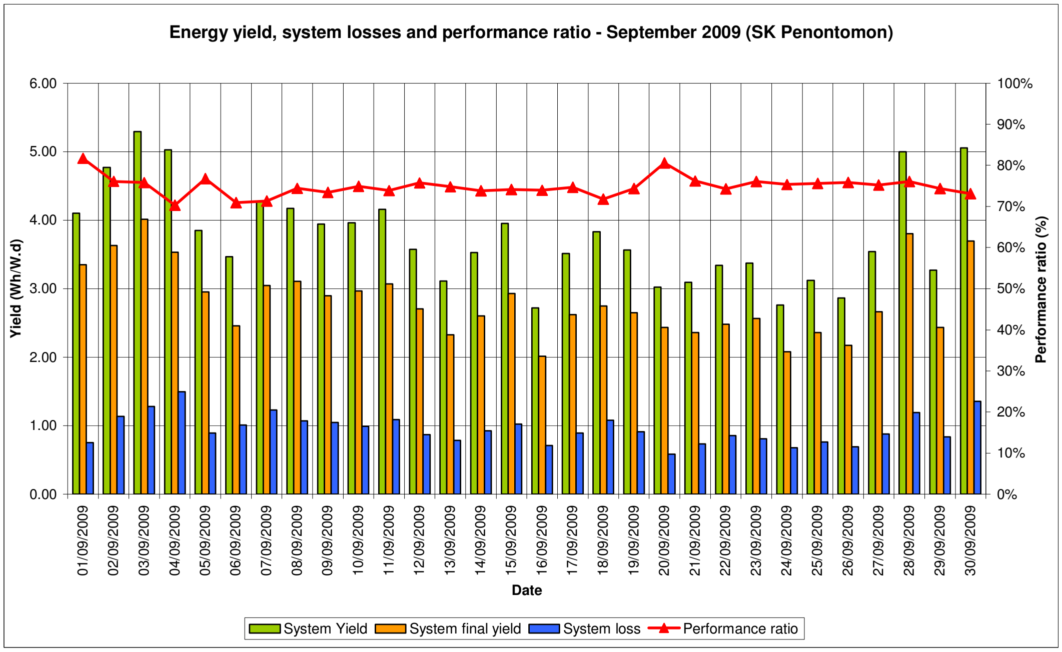

Figure 9.1 : Energy yield, system losses and performance ratio of the solar hybrid system at SK Penontomon in September 2009.

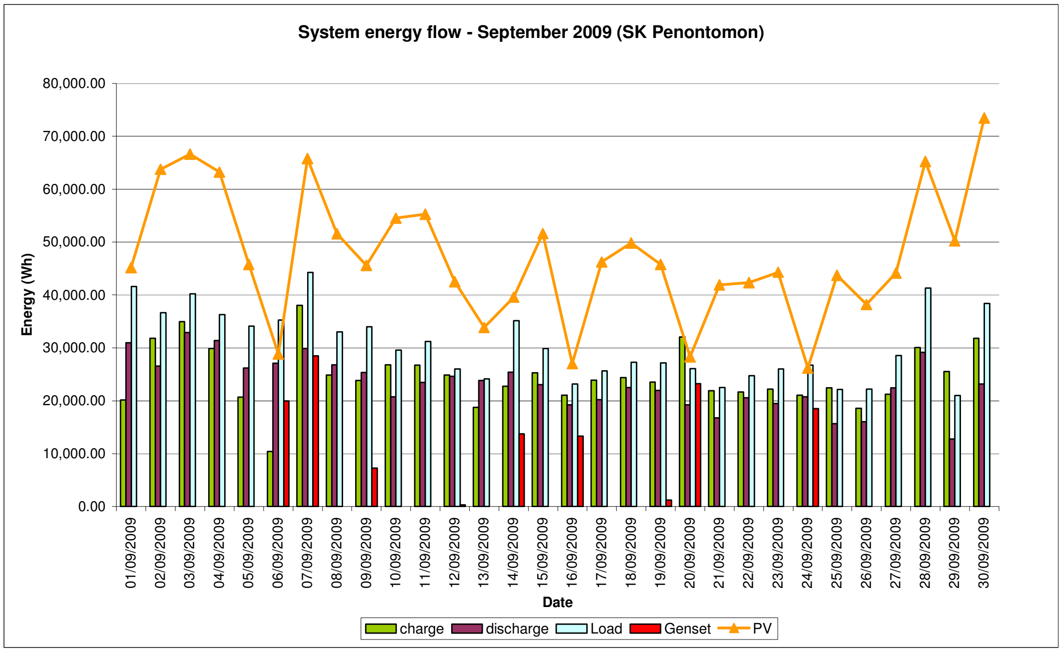

Figure 9.2 : The system energy flow of the solar hybrid system at SK Penontomon in September 2009.

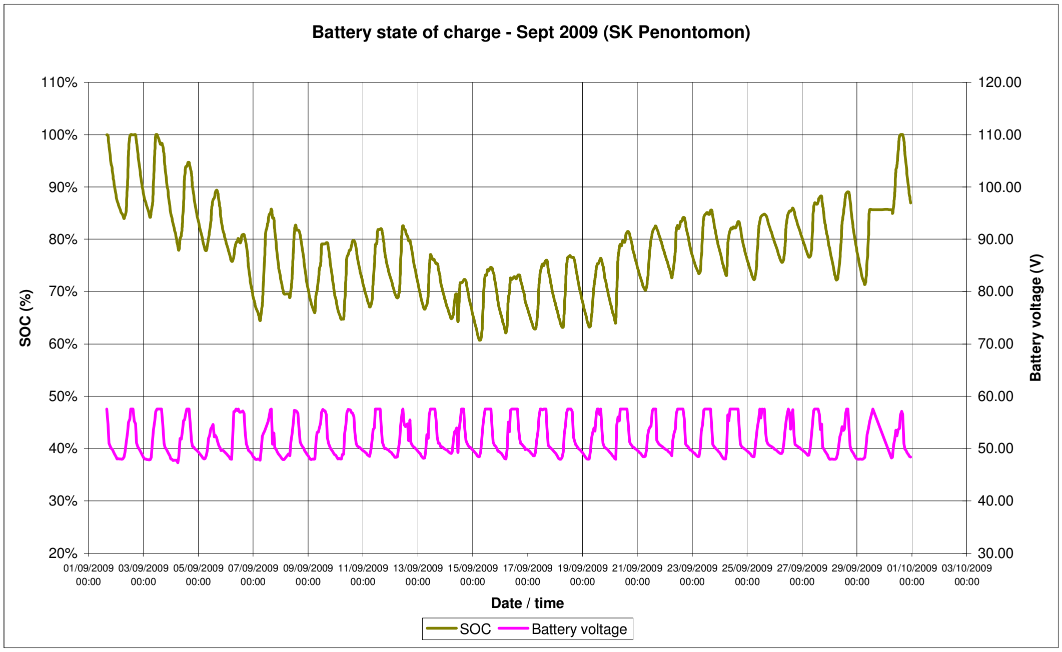

Figure 9.3 : The battery state of charge (SOC) level of the solar hybrid system at SK Penontomon in September 2009.

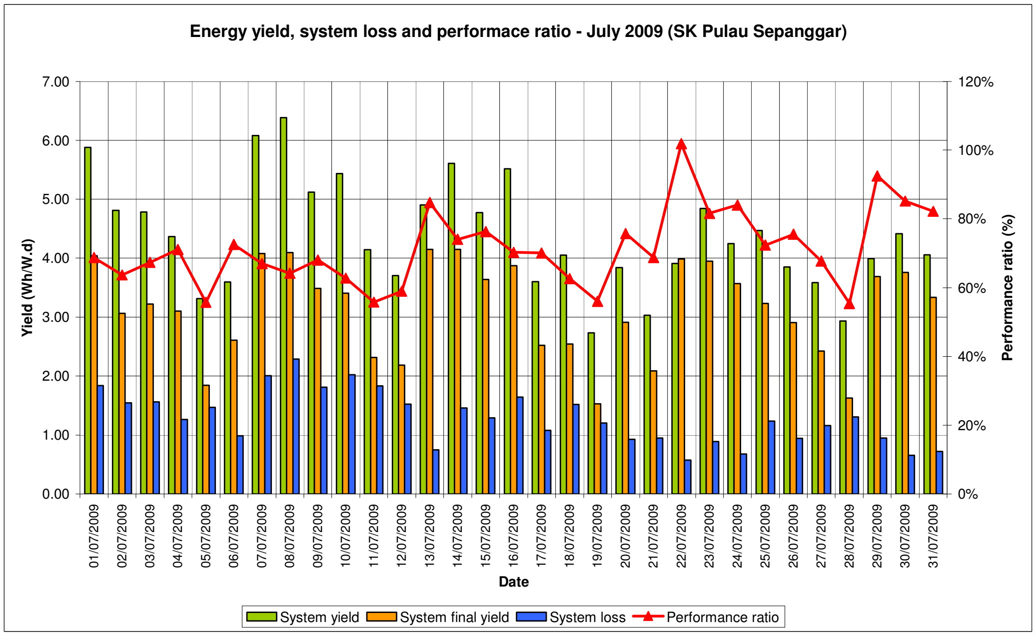

Figure 9.4 : Energy yield, system losses and performance ratio of the solar hybrid system at SK Pulau Sepanggar in July 2009.

Table 9.1 : System components and configurations for both schools.

Components	Parameters	Unit	SK Penontomon	SK Pulau Sepanggar
PV Panel	System Power Rating	*Wp*	20,000	25,000
	Quantity	*no.*	120	152
	Brand/Make		Solar World	Solar World
	Model		SW 165	SW 165
	PV System Voltage	V_{DC}	70	70
	Pmax	*Wp*	165	165
	V_{MPP}	V_{DC}	35.3	35.3
	I_{MPP}	*A*	4.7	4.7
	Cell Type		Mono	Mono
	Panel Dimension	*L (m) x W (m)*	1.81 x 0.81	1.81 x 0.81
Inverter	Brand/Make		Conergy	Conergy
	Model		Xtender-8000	Xtender-6000
	Quantity	*no.*	3	6
	Rated battery voltage	V_{DC}	48	48
	Rated power per unit	*W*	6,400	4,800
Charge Controller	Brand/Make		Morningstar	Morningstar
	Model		TriStar-60	TriStar-60
	Rated Current	*A*	60	60
	Quantity	*no.*	8	10
	Nominal system voltage	V_{DC}	48	48
Battery	Brand/Make		FIAMM	FIAMM
	Model		LM 3500	LM 1875
	Battery type		Tubular vented lead acid, 2V	Tubular vented lead acid, 2V
	Quantity	*no.*	24	48
	Battery system voltage	V_{DC}	48	48
	Nominal voltage	V_{DC}	2	2
	Nominal capacity	*Ah*	3500	1875
Diesel Generator	Brand/Make		FG Wilson	FG Wilson
	Genset Model		P27P1	P40P3
	Output Rating	*kVA*	27	40
	Phase		3 phase	3 phase
	Frequency	*Hz*	50	50
	Fuel consumption	*litre/hour*	6.2	10.3
	Fuel tank	*litre*	2,000	2,000