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

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Abstract: The impact of the implementation of solar hybrid system which was installed at Penontomon Primary School in Sabah, Malaysia has been analyzed in this paper. The project was initiated by the Malaysia's Ministry of Education with the target to electrify rural schools that do not have grid connected electricity in Sabah with alternative power supply; ie, the renewable energy. The paper looked into the users' experiences, technical and the economical aspects of the system and found that alternative resources from renewable energy 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 pupils and teachers by creating more comfortable lifestyle and conducive learning environment.

Keywords: *Solar hybrid, Rural schools, SCADA, Battery, Inverter*

1. Introduction

Malaysia, although moving rapidly towards being a developed nation, has a considerable number of under-developed rural areas. Most of these are tiny pockets of inhibited villages, sprawling over large areas of Sabah and Sarawak (the Borneo Island part of Malaysia). In general, basic infrastructures are inadequate and grid connected electricity supply is the major one. Out of more than 10,000 schools in Malaysia, 809 in Sabah and Sarawak still lacked 24-hour electricity supply and have to rely on decentralized diesel generator as the main source. The main reasons can be attributed to (1) the remote locations of these villages and (2) the community size is very small. These factors caused the investment cost for grid supply prohibitively expensive and un-economic. The cost of electricity using this method is very high – primarily due to the fuel transportation to the sites. Furthermore, consistent electricity cannot be guaranteed because of the climatic and geographical conditions that may hamper the fuel supply route. To ensure that these areas are not lagging behind in the country's modernization strategy, the Ministry of Education (MOE) has initiated a large electrification program for rural schools in Sabah. It is recognized that stable and reliable electricity supply is the key element for conducive learning environment and enables the use of computers, communication system, lighting and etc [2]. The government has allocated over RM1.15 billion (USD365 Million) to improve the basic infrastructure [1]. Fittingly, electricity supply is given top priority.

Despite the fact that the program has been going on for two years, there is no documented literature describing the design methodology, performance analysis, economics evaluation and the social impact of the installed systems. It is envisaged that the lessons learned from these experiences can provide valuable guidelines for future rural electrification programs using SHS. Hence this work is carried out. The study can be divided into two parts (1) to analyze the technical and the economical aspects of the system design and daily operation based on real data (2) to study and analyze the impact of the SHS on their lifestyle and the learning environment.

2. 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.

2.1 Impact On The Solar Hybrid System

Structured questionnaires were distributed to the 40 selected respondents, which consists of the teachers and pupils. 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 installed and how the system does affects their life and the learning environment.
b) Comparison of the users' knowledge of renewable energy especially the Solar Hybrid System before and after the installation.
c) Load management strategies which are being exercised by the users.
d) Users' opinions on how the system can benefit the entire community should the same system implemented for their village as well.

2.2 Implementation and Operation of the Solar hybrid System

The second part of the methodologies determines the Solar Hybrid System performance technically and economically. The design and actual load analysis compares the design load profile and the actual load profile (average) and the system operation analysis answers 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. The economic analysis includes both costs and benefits of the system. Parameters like investment cost, operating cost and cost of energy are used to measure the beneficial of the system as compared to the conventional diesel generator [4].

3. Solar Hybrid System

The solar hybrid system integrates two power sources. The system is designed to supply electricity for every building in the school like class rooms, computer lab, guard house and teachers' quarters. For the purpose of the analysis, Penontomon Primary School which is located in Keningau District in Sabah (N 4°52.73' E 116°15.9') has been identified to be the sample site for evaluation and analysis processes.

3.1 Description of Loads & Load Profile

The total installed rated load power for SK Penontomon is 15.23 kW [6]. The load usage has been distributed over 24 hours load profile which used to identify the maximum peak load during the day. 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. While at night it requires 30.47% of the daily energy demand (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.

3.2 System Configuration

As shown in Figure 1 below, the 20 kW_p PV array is used to supply power to the load and to charge the battery during day. Priority will be given to satisfy the day time load. A 3,500 Ah tubular vented deep cycle lead acid battery bank is used for storage and supply power to the loads mostly during night. The bidirectional inverter converts the DC-AC voltage and vice versa. If there were insufficient power from the PV to charge the battery, the 27 kVA diesel generator will turn on automatically. Moreover, excesses electricity from the generator will be used to electrify the loads. The generator is configured to be automatically turned on for one hour every week to warm up and also once a month for several hours for battery equalization.

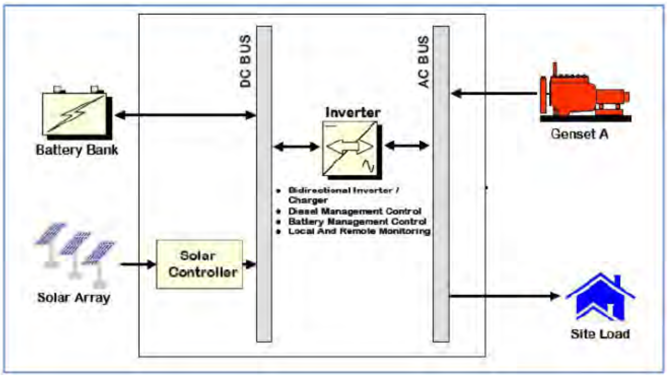


Figure 1 : The solar hybrid system configuration diagram [6].

4. Results and Analysis

4.1 User Experiences

4.1.1 Knowledge

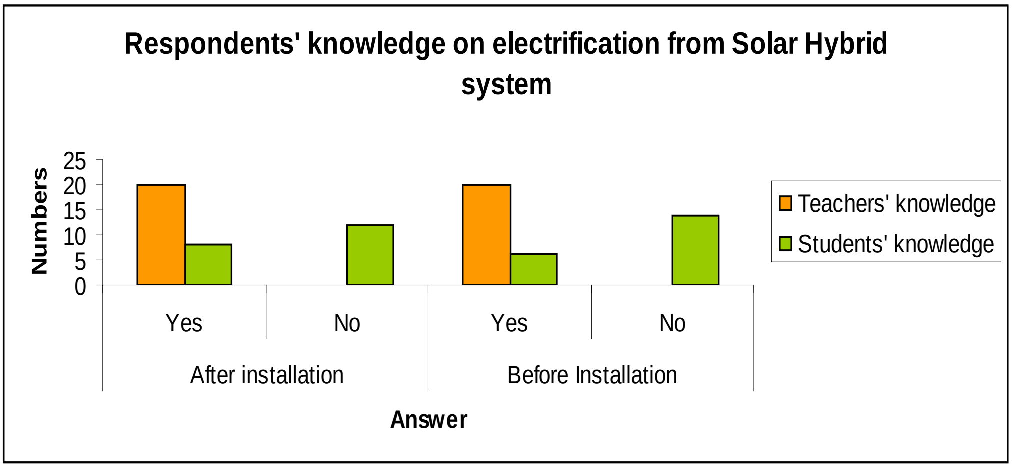


Figure 2 : Respondents' knowledge on electrification from solar hybrid technology system.

All of the teachers and only six pupils have some knowledge of the Solar Hybrid System before the installation of the system. The numbers of the pupils that gain information of the system after it is in operation increasing by 10%.

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

35% of the respondents have seen the technology before at other places/villages. The technology was installed for village communities in several rural electrification programs like

Solar Home System (SHS) by Ministry of Rural and Region Development and Solar PV System for Rural ICT Centre by Ministry of Energy, Water and Communication.

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

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

4.1.2 User Training

At least a teacher from each school is required to attend training on solar hybrid technology. The teacher will be responsible to give the information on the technology to the other users. It is found out that only informal explanation was given to the users. As shown in figure 3 below, only 24 respondents were given informal information and eighteen respondents understand well about the technology, while another six respondents requested for more explanation and formal training.

The main barrier in implementing PV system in any rural electrification program is the operation period. PV system and its implementation are frequently looked upon in a very simplistic manner by a number of people which has resulted in a large number of failures [4]. Proper transfer of technology training program is required for the end users because the awareness and knowledge on the system technology are equally as important as the adequate financing and institutional framework.

4.1.3 Load Management Strategies

All of 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 would 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 would be turned off when there is no occupant in the room, except for the equipments that need 24 hours operation like refrigerator.

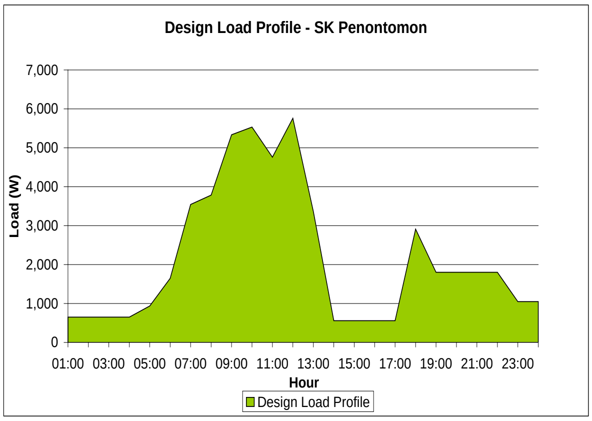
4.1.4 Users' Opinions

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

The respondents believe that the nearby village should be connected by 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 areas in economy, education, lifestyle, communication and etc.

4.2 Design and Actual Load Analysis

Figures 3 and 4 below show the comparison of the load profile for both schools.



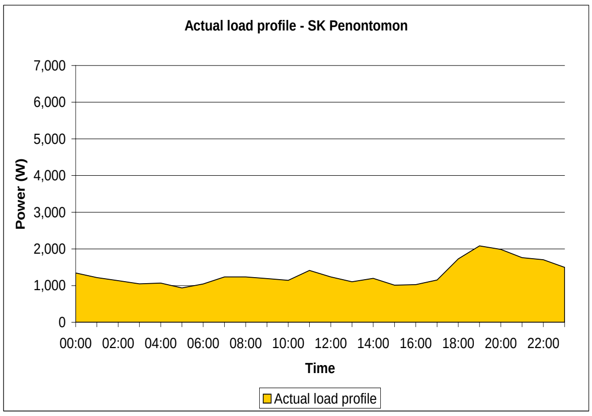


Figure 3 and 4 : The design load profile [6] (left) and t he actual load profile (right) for SK Penontomon. The actual load profile was calculated based on the load consumption in September 2009 recorded from the JSCADA system.

The actual base load (minimum load) for the school is 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 at night instead of day as assumed in the design profile.

The total daily energy consumption was less 30% than the design values. The actual energy consumption at SK Penontomon was higher at night. The reason is the teachers' quarters in SK Penontomon contribute 41% of the total load sharing.

4.2 System Operation Analysis.

Parameter that can determine the reliability of the PV system to supply electricity to the load is *Loss of Load (LL)*. Moreover, another two useful parameters 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" [3]. "C_S is the maximum energy that can be extracted from the accumulator divided by the daily energy consumption of the load" [3]. Hence the equations will be;

$$C_A = \frac{E_{PV}}{L} \tag{1}$$

$$C_S = \frac{C_U}{L} \tag{2}$$

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 [3], 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 the amount of energy provided by the solar technology system divided by the total energy required [5]. This shows the system dependency on the diesel generator as compared to the solar PV.

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 [3]. In this study, one month energy efficiency is calculated.

Table 1 : Summary of the system energy parameters for both systems.

Parameter	**Symbol**	**SK Penontomon**
Loss of load	LL	0 %
PV Generator capacity	C_A	1.57
Accumulator capacity	C_S	5.76
Solar Fraction	SF	92%
Battery Energy Efficiency	η_{Wh}	94%

The system satisfies 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 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 can work without any major problems.

4.4 Economic Analysis

Generally, for either systems (diesel generator only or solar hybrid system), the Cost of Energy (COE) is depending on the size of the system. A bigger system capacity reduces the COE. But, it will also increase the investment cost.

The operating cost of both systems shows that the client will be burden by the higher cost for operating the diesel generator system compared to the solar hybrid system. For solar hybrid system, the service and maintenance routine should be done at least twice a year excluding the corrective maintenance. The generator has less services every year since the operation hours is minimum.

Table 2: Result from Homer simulation on the economic aspect [4].

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

Figure 5 below is the total cost of the project in twenty five years of its lifetime. It is based on the components cost including their replacement cost, civil works of building the power house, electrical works especially for mini grid installation, fuel cost and the operation and maintenance costs. Replacement of batteries is considered in every 6 years, diesel generator in 8 years and inverter and charge controller in 15 years [3]. It is clearly shows that the batteries are the most important component of the system as it contributes 45% of the lifetime project cost.

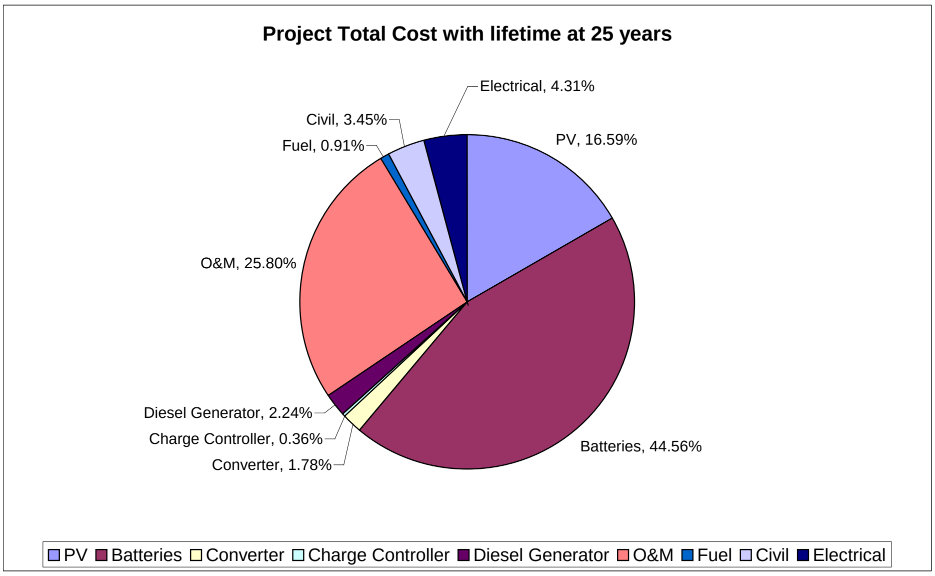


Figure 5 : Project total cost of the solar hybrid system. The project lifetime is at 25 years.

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

5. Conclusion

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 pupils and teachers by creating more comfortable lifestyle and conducive learning environment.

The measurements and simulation of the system shows that the solar hybrid system can produce reliable power supply to meet the electricity need of rural schools. 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 costs less than a solar hybrid system, but the fact that its operating costs in providing a proper service and maintenance makes the system less favorable compared to the solar hybrid system. The study shows that the heart of the system lies on the batteries as it contributes almost half of the total lifetime cost and almost half of the daily load consumption is served by the batteries. Improper conducts on t he system may directly affect the batteries performance which may lead to the failure of the system.

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