Alternative Utilizations of Photovoltaic Modules from Solar Home System, Thailand

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Abstract

Since, the SHS program started in year 2003, approximately 200,000 units of SHS have been installed. Unfortunately, many survey studies indicated that more than 20 percent of SHS were not working properly, due to damages of system components such as, battery, charge controller, inverter, and lighting system, but, almost of PV modules are working perfectly. So, this paper presents a practice to recover the potential of PV modules, which have been abandoned. The paper describes alternative utilizations of PV modules, including photovoltaic stand alone system (PVSS), photovoltaic hybrid system (PVHS), and photovoltaic grid connected system (PVGS). This paper also describes about alternative system selection guideline and the system advantages. In 2009, Tambon Shomphoo, which located in Nernmaprang district, Phisanuloke province, has been selected as a study site. From the survey data show that there were about 20% of SHS was malfunction or 114 PV modules or 14 kW_p of alternative system was available. The PVSS was selected from the alternative system guide and economic of the system was assessed. The system can produce 18,391.90 kWh/y. The life cycle cost is about 3,222,430Bath and COE is 8.76 Bath/kWh.

Key Words: *Photovoltaic, Solar Home System*

1. Introduction

Rural areas of developing countries are almost at a disadvantage in a term of access to electrification. There were about 1.6 billion people in the world who live without electricity and about 0.9 billion live in Asia [1]. In Thailand, there were about 290,000 households in remote those livings off-grid connection [2]. Additionally, extending an electricity grid to households in rural areas has been considered as un-economical investment since it costs seven times more than for grid electricity in urban areas [3]. However, in a modern world, access to electricity is almost taken as a basic human right. It is possibility to improve productivity or provide welfare benefits, at least for lighting and communication. For such those reasons, in 2003, Thai government announced Solar Home System (SHS) program for installations of approximately 200,000 units of the SHS, which each unit consists of 120 Wp photovoltaic module, charge controller, inverter, battery, and a couple of fluorescent lamps, to non-electrification areas. The installations have begun in April 2003 and finished in April 2005. The budget of the program was about 7.6 billion Bath (33 Bath = 1 US$), which funded by Sub district Administration Organization, Ministry of Interior [2]. The program added about 24.36 MW to total installed solar electricity systems, which stood at just 6 MW in 2003.

In 2007, after 2 years of the SHS installations were completed, cumulative failure of SHS units were over 20 percent [4, 5]. The causes of failures could be classified as user error, installation error, manufacturing error, and natural disasters, which caused damages to the SHS components. The broken components composed of 34.4 percent of lighting set, 32 percent of inverters and charge controllers, and 30.5 percent of battery, while only 3.1 percent of photovoltaic modules responded for the system failure [6]. Moreover, the sustainability of the SHS program was treated by maintenance cost that was between 130 and 300 Bath per month [4], while user’s willing-to-pay was about 30 Bath per month [5] (33 Bath = 1 US$). There would have been a wide spread of SHS component failures after system component warranty has expired. Due to, limited life time of the system components for instance 2-5 years for battery, fluorescent and ballast, 5-10 years for charge controller and inverter, while the longest lifetime is 20-25 years of photovoltaic modules. However, the most wealth of the system is the photovoltaic module, which still has potential to generate energy. So, this paper would suppose the alternative utilizations of photovoltaic modules from the nonfunctional SHSs.

The SHS programs were distributed to all regions of the country includes Central, Northern, North-Eastern, and Southern. In the central region SHS installations tend to much settle in the far west border, that is a lesser development area. Only few were installed in center region and the south-eastern region. Overall, SHS are about 17,134 units or 2.06 MW makes this region is the least SHS installations of Thailand. The northern region is mountainous and was traditionally the most heavily forested area of the country. This part is the most rural and isolated regions in Thailand with the lowest average population density. There are about 96,718 units of SHS or 11.6 MW were installed, consider as the most SHS installation of Thailand. The north-eastern region constitutes approximately one third of the area of the country. Largely owing to lower and erratic rainfall and poorer soils than in other parts of the country, the north-eastern provinces have the lowest per capita income in the country. Approximately one third of the population of Thailand lives in the north-eastern, there are 47,174 units of SHS or 5.66 MW were installed. While the southern region which has the highest amount of rainfall of the country. Its terrains are varies includes plain, mountainous, rain forest, deforested area, beach and islands. The SHSs distributed to these rural areas, especially non electricity islands, about 41,974 units or 5.04 MW

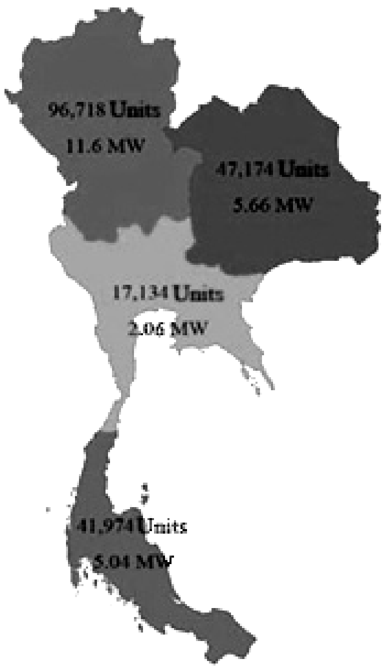

Fig.1 Distribution of SHS in Thailand [6]

In many failure cases cause from the technology gap and service cost. Although SHS technology has been chosen because it is easy to use for most people, but the introduction of SHS to rural villagers, which are highlanders or islanders, is different. They do not understand the technology or cannot properly use SHSs. These are increasing number of system failures. From our survey result, about 20 % of the systems are inactive or not working properly causes from defections of PV module, charge controller/ inverter unit, battery, and lighting systems, the portion of the causes showed as following.

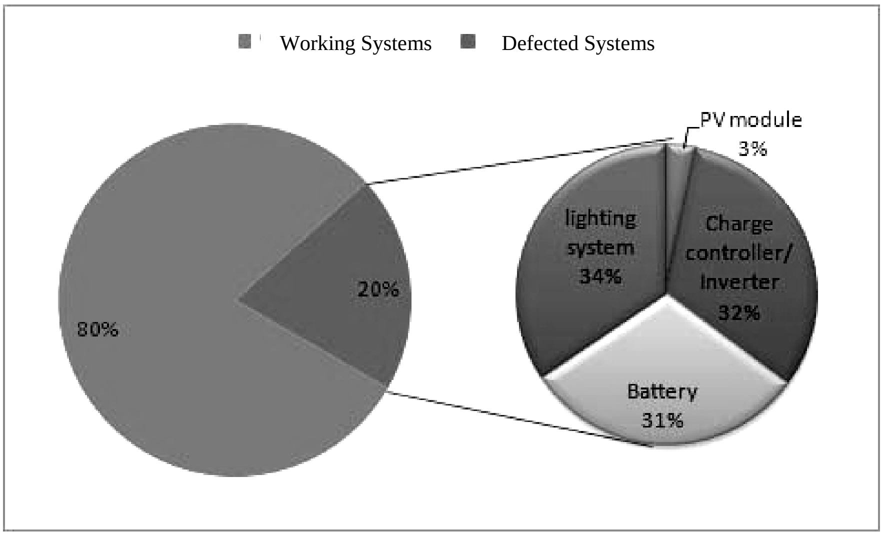

Fig.2 Percentage of defected component from failure SHS [6]

Only 3 percent from PV module caused the system failures. Today, the system failures are about 20 percent or more. So, there is about 4.7 MW of PV module potential is useless. While, Thailand experiences high level of solar radiation, with average daily solar radiation is 5.1 kWh/m^2 [7]. The maximum is between 5.6-6.7 kWh/m^2 in April and May. The highest solar radiation regions are northeastern and partial of central, covers 14.3% of country. Its average daily solar radiation is between 5.3-5.6 kWh/m^2. Moreover, it is more than 50% of Thailand receives the average daily solar radiation between 5.0-5.3 kWh/m^2. The maximum average daily solar radiation is in April and May, which is about 5.6-6.7 kWh/m^2. Only 0.5% of country receives average daily solar radiation less than 4.4 kWh/m^2. This resource is relatively predictable and well distributed throughout the country with some regional variations. This amount of solar radiation is makes sense for keeping the photovoltaic system development in any parts of Thailand.

On the other hand, since the local government, the owner of SHSs, may not endorse SHS subsidies of they have higher priority spending need in the areas or want to spending budget for another public use. The users have to pay for maintenance and service by themselves. The maintenance cost varies from a dollar for light bulb to hundreds dollar for an inverter. Moreover, the service fee for such a remote area is expensive than usual. Unfortunately, the average user willing to pay is only 30 Bath per month [5]. This mean they cannot properly use or maintain the system and cannot pay for the service fee, too. These problems are leading Thailand SHS program to ruin. So this paper will purpose alternative uses of SHS modules, especially for remote public uses that should be run by local government.

2. Alternative Photovoltaic Systems

This paper proposes 3 types of photovoltaic system which are suitable for Thailand or other developing country. All systems adopt photovoltaic modules from SHS to become a part of the new system. The proposed systems included Photovoltaic Stand-Alone System (PVSS), Photovoltaic Hybrid System (PVHS), and Photovoltaic Grid Connected System (PVGS).

2.1 Photovoltaic Stand-Alone System (PVSS)

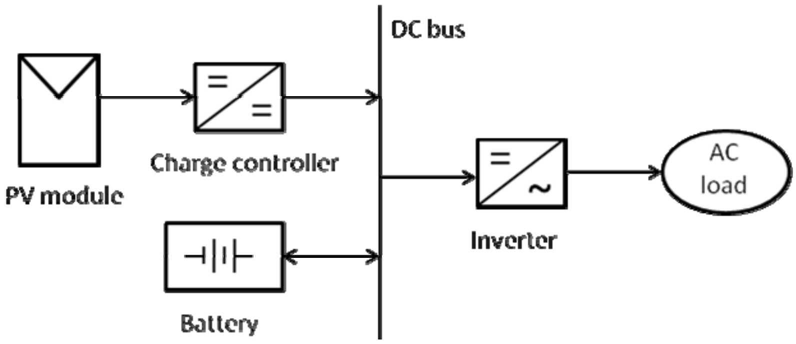

Fig.3 Photovoltaic Stand-Alone System (PVSS) [6]

The system components include photovoltaic modules, charge controller, inverter, and battery as showed in figure 3. The Solar Home System (SHS) can be considered as a PVSS, but SHS is only 120W-system. The PVSS is suitable for any utilization, which its annual energy consumption is less than 1 MWh [3]. Under normal operation, during daytime when there is adequate solar insolation, the load is supplied with DC power while charging the battery, simultaneously. When sizing the solar power system, the DC power output from the PV arrays should be adequate enough to sustain the connected load and the battery trickle charge requirements. Battery storage sizing depends on a number of factors, such as duration of uninterrupted power supply to the load when the solar power system is inoperative, such as nighttime or cloudy days. Over sizing design leads to low performance ratio (PR ranges from 0.1-0.6), but increases reliability of PVSS [8].

2.2 Photovoltaic Hybrid System (PVHS)

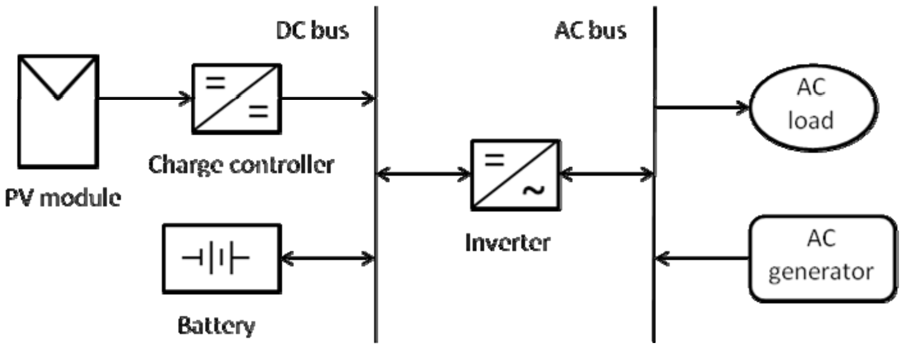

Fig.4 Photovoltaic Hybrid System (PVHS) [6]

PVSS is consists of PV module, Charge controller, inverter, battery, and generator. The generator size can be varied from huge diesel generator sets to simply agricultural engine with generator depend on energy demand. Engines that drive the motors typically operate with diesel. Fuel tank sizes vary with the operational requirements. Almost storage capacity to operate the generator should be up to 48 hours. The proper annual energy demand, which suitable for the PVHS, should between 100 kWh and 10 MWh [3]. The performance ration of a PVHS is normally between 0.3-0.6 [8].

2.3 Photovoltaic Grid Connected System (PVGS)

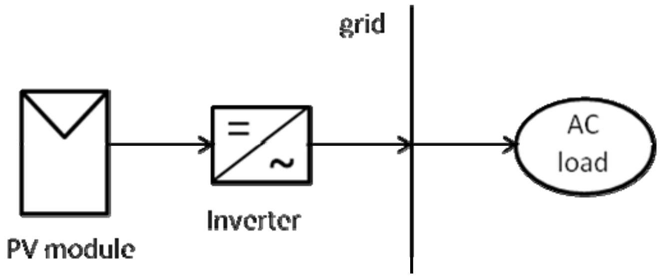

Fig.5 Photovoltaic Grid Connect System (PVGS) [6]

PVGS is the power cogeneration system that configuration is similar to the hybrid system. The essence of a grid connected system is meters. Standard service meters are odometer type counting wheels that record power consumption at a service point by means of a rotating disc, which is connected to the counting mechanism. For Grid connection system, it needs another meter for record power supply to grid utility. Other important prospect for consideration is electricity buying and parallel generation regulations. The PVGS is suitable for any utilization, which its annual energy consumption is more than 0.5 kWh [3]. The Performance ratio for PVGS ranges from 0.25-0.9, the system PR goes wide, since the system size is vary from 0.5 kW lighting system to 1 MW PV power station. However, the maintained PV systems operating well show an average PR value of typically 0.72 [8].

The alternative utilizations, which are proposed, are not just bringing PV modules of defected systems to generate electricity for public utilizations, such as water pumping, water purification, electrification of rural schools, religious institutions, health center, communication, and operating computer. These utilizations are not only improving the villager’s quality of life, but also improving the system efficiency. Since, the larger system capacity is also higher efficiency, for instance, no-load power loss of a 150W-inverter is about 10% - 20%, while the larger inverter ranges from 5% - 15% [9]. The modified sine wave inverter was selected for SHS for economic reason, while the public utilization, which has more economic of scale, can use a true sine wave inverter that are more suitable for resistive load. Typically, an electric motor will use for 15% - 20% more power with a modified sine wave than with a true sine wave [4]. However, inverters are also much less efficient when used at the low end of their maximum power. Most inverters are most efficient in the 30% - 90% power range [10]. Many successful systems in Africa and Asia [11] have power generation capacity range from 800 W to 1.5 kW. Like the inverter case, shallow cycle battery also was selected to SHS program for economic reason, with larger scale it can be replaced with a deep cycle battery, which is more suitable and longer of lifetime.

Another advantages of alternative utilization program is low investment cost compares to other PV systems, since approximately 50 percent of PV investment cost comes from PV module [5], but for alternative utilization, PV module will be gathered free of charge from defected system. For environmental aspect, this program will reduce green house gas from reciprocation engine or even kerosene lamp, comparing carbon dioxide emission 5.3 g/kWh of PVSS to 300 g/kWh of oil [3].

3. System Selection

To convert the old SHSs to the new alternative utilization systems there are many factors should be considered. Thus, to make it easier for decision maker, sub district administration organizations, we suppose a simple diagram, as followed, to use as system selection guide to select a suitable PV system to vary areas.

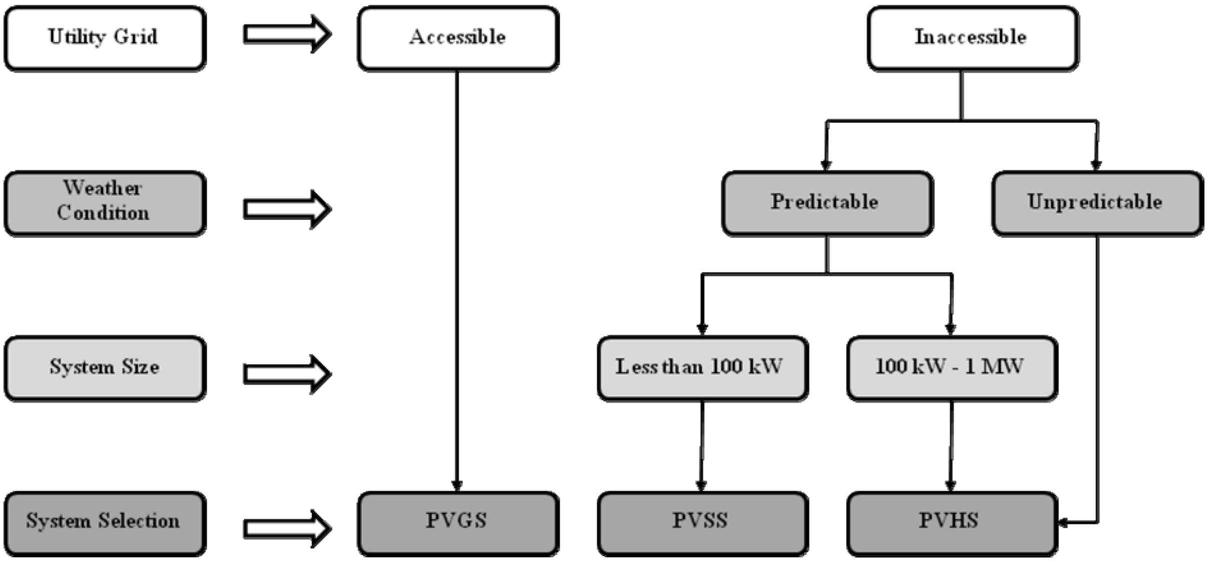

Fig.6 System selection guide

The diagram consists of 3 decision stages; the first stage is to consider about a utility grid access. At those day when the SHSs have been established, there were not any single SHS is access to utility grid because SHS program's objective is to provide electricity to people who live in remote place. However, it's possible that utility grid will extend out and making some locations access to the utility grid then PVGS will be considered. If there is still inaccessible to the utility grid then we will go to 2nd stage, where area weather condition will be considered. Some areas in Thailand are rainy especially Southern part, where the rain is unpredictable or comes too often then leads the daily average solar radiation value to less than 200W/m^2.day [10]. These will decrease quality of electricity power and lead systems to unnecessary oversize and investment. In this case PVHS will be considered to exploit its higher reliability. If the weather is predictable go through 3rd stage where the system size will determine either PVSS or PVHS is appropriate to economic of scale. USAID, office of energy, environment and technology, recommends, PVHS for 100 kW system and higher whereas the smaller system should be PVSS [12].

Finally, the performance of every system can be optimized by improving efficiencies of components by 1) the selection of high efficiency components 2) avoiding of undersized wiring 3) avoiding MPP inverter losses by optimum components matching 4) avoiding high module temperatures by suitable measure of module integration into PV panel foundation 5) avoiding array coverage due to dirt and 6) reducing array shading as much as possible during the planning phase.

4. Economic Assessment of Site Selected

The selected study site is Tambon Shomphoo which located in Nernmaprang district, Phisanuloke Province. The area likes other remote area in Northern part of Thailand, mountainous geography. The utility grid was inaccessible while the weather condition is not too harsh. The average daily solar radiation-horizontal is 5.17 kWh/m^2. There were 407 SHSs or 48.84 kW$_p$ has been installed in the area. From our empirical study in 2009, we found many defected systems. The major cause came from battery and charge controller/inverter unit which can be expressed in percentage at 29.8% and 27.27% in the order. So, there were approximately about 14 kW_p or 114 PV modules potential are available. In this case, the local government should select PVSS for alternative utilization of PV modules. To evaluate the energy output from 14 kW_p PVSS using followed equation.

$$PVE = H_t \times A \times \eta_{pv} \times \eta_{sys} \quad (1)$$

Where:

H_t is average solar radiation, 5.17 $kWh/m^2/d$

A is area of PV module, which is 0.992 m^2/module [13] or 113.09 m^2 for the system

η_{pv} is efficiency of PV module, which is 12.6%. [13]

η_{sys} consists of η_{Inv}, η_{chg}, η_{batt} which are efficiency of inverter, charge controller, and battery in the order. In this case, they will be assumed as 95%, 90%, and 80%.

So, the energy output of 14 kW_p PVSS is about 50.39 kWh/d or 18,391.90 kWh/y. Since, the system must be economic. The project economy based on conventional life cycle costing economics.

Life cycle cost [14]

LCC determines which power supply systems can be cost competitive with other energy options. The ordinary equation for described LCC is fallowing.

$$LCC = C_{Cap,tot} + C_{ann,tot} + C_{Repl,tot} + C_{Sal} \quad (2)$$

Where:

$C_{Cap,tot}$ is total capital cost, $C_{ann,tot}$ is total annual cost, $C_{Repl,tot}$ is total replacement cost, and C_{Sal} is salvage cost. In this case the system components are properties of local government, which cannot be salvaged. So the LCC of the PVSS alternative utilization is fallowing.

$$LCC = C_{Cap,tot} + C_{ann,tot} + C_{Repl,tot} \quad (3)$$

The LCC of the 14 kW PVSS, which consists of 114 PV modules, power conditioning (14kW charge controller/inverter), 50 kWh battery storage. The market price of PV module is 150 Bath/W, power conditioning is 5,000 Bath/kW, battery is 8,000 Bath/kWh. So the components of the system worth 2,282,000 Bath.

PV system BOS, installation and shipping, and operation & maintenance cost are about 15%, 10%, and 15% of component cost in the order, and Replacement costs are calculated further.

Total capital cost [14]

$$C_{Cap,tot} = \cancel{C_{Cap,PV}} + C_{Cap,Inv} + C_{Cap,chg} + C_{Cap,Batt} + C_{Cap,BOS} + C_{Cap,Inst} + C_{Cap,Oth} \quad (4)$$

Where:

$$C_{Cap,Inst} = C_{Inst,PV} + C_{Inst,Inv} + C_{Inst,chg} + C_{Inst,Batt} \quad (5)$$

$$C_{Cap,Oth} = C_{Ship,} + C_{Oth} \quad (6)$$

Where $C_{Cap,Inv}$ is the capital cost of inverter, $C_{Cap,chg}$ is capital cost of Charge controller. $C_{Cap,Batt}$ is capital cost of battery, $C_{Cap,BOS}$ is capital cost of balance of system. While, the capital cost of PV is absent, due to existing of photovoltaic modules from the solar home project. In this case, the total capital cost is calculated as followed.

$$C_{Cap,tot} = \cancel{2,100,000} + 14(5,000) + 50(8,000) + 385,500 + 257,000$$
$$= 1,112,500 \text{ Bath}$$

Annual cost [14]

These consist of regular maintenance costs over the years. The actual costs vary to location of installed system.

$$C_{ann,tot} = C_{ann,PV} + C_{ann,Batt} + C_{ann,Inv} + C_{ann,Chg} + C_{ann,Oth} \quad (7)$$

Where $C_{ann,PV}$ is annual cost of PV arrays, $C_{ann,Batt}$ is annual cost of battery storage, $C_{ann,Inv}$ is annual cost of inverter, $C_{ann,Chg}$ is annual cost of charge controller, $C_{ann,Oth}$ is annual cost of other. In this case, the summary of annual costs in the system lifetime is fixed to 15% of main component cost, which is 385,500 Bath.

Replacement cost

Replacement costs are more complicate. They are not annual payment. The main components of the system have to be replaced during the life time. To convert the replacement cost into annual cost

$$C_{Repl,tot} = C_{Repl, Batt} + C_{Repl,Inv} + C_{Repl,chg} + C_{Repl,Oth} \quad (8)$$

Where:

$$C_{Repl,Batt} = C_{Batt}\ x\ (F/P,i,n) \quad (9)$$
$$C_{Repl,Inv} = C_{Inv}\ x\ (F/P,i,n) \quad (10)$$
$$C_{Repl,Chg} = C_{Chg}\ x\ (F/P,i,n) \quad (11)$$
$$C_{Repl,Oth} = C_{Oth}\ x\ (F/P,i,n)$$
$$F = P(F/P,i,n) = P(1+i)^n$$

Where F/P is the compound amount, F is future money, P is present money, n is the component lifetime in year, i is the inflation rate. In this case inflation rate is 2%, only $C_{Repl,Batt}$, $C_{Repl,Inv\&Chg}$ in year 5th, 10th, and 15th are calculated as followed.

$$C_{Repl,Batt} = C_{Batt}\ x\ (F/P,i,n)$$
$$C_{Batt}\ x\ (F/P,2,5) = 400000 \text{ x } 1.1041 = 441,640$$
$$C_{Batt}\ x\ (F/P,2,5) = 400000 \text{ x } 1.2190 = 487,600$$
$$C_{Batt}\ x\ (F/P,2,5) = 400000 \text{ x } 1.3459 = 538,360$$
$$C_{Repl,Inv\&Chg} = C_{Inv}\ x\ (F/P,i,n)$$
$$C_{Inv\&Chg}\ x\ (F/P,2,5) = 70000 \text{ x } 1.1041 = 77,287$$
$$C_{Inv\&Chg}\ x\ (F/P,2,10) = 70000 \text{ x } 1.2190 = 85,330$$
$$C_{Inv\&Chg}\ x\ (F/P,2,15 = 70000 \text{ x } 1.3459 = 94,213$$

Cost of energy (COE) [14]

$$COE = LCC/(E_{prod}\ x\ SysLife) \quad (12)$$

The COE of the 14 kW PVSS is calculated as followed.

$$\begin{aligned} COE &= LCC/(E_{prod}\ x\ SysLife) \\ &= (C_{Cap,tot} + C_{ann,tot} + C_{Repl,tot})/(18,391.90 \text{ x } 20) \\ &= (1,112,500 + 385,500 + 1,724,430)/(367,838) \\ &= 8.76 \text{ Bath/kWh.} \end{aligned}$$

5. Conclusion

In next few years, many SHS will be more abandoned, because the user can not afford the system maintenance costs. The local government, the owner of SHSs, should have a plan to cope the situation. It is not reasonable for the local government to bring the fiscal fund to support any individual. In this case is Tambon Shomphoo, there are 14 kW_p of PV module are available. If local government gathers those PV modules then settle a 14 kW_p PVSS .The system can produce 18,391.90 kWh/y. The life cycle cost is about 3,222,430Bath and COE is 8.76 Bath/kWh. So, the alternative utilization is a practice to manage those abandoned SHSs, which PV module in the system still in high potential. The alternative utilization could be PVSS, PVHS, and PVGS that each system has its own appropriate condition which are described in the paper. Moreover, the alternative utilization is not only recovering the loss of resources but also improve the villager's quality of life and environment.

6. Acknowledgement

Special thanks to National Research Council of Thailand (NRCT) for sponsorship of Development and Improvement of Solar Home System Application Project and also thanks to the School of Renewable Energy Technology (SERT), Naresuan University for any kind of encouragements.

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