Photovoltaic Rural Electrification in Thailand

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ABSTRACT

Photovoltaic energy systems have been introduced in rural areas during the past several years. This article presents a picture of photovoltaic utilizations in Thailand. Activities and experiences on various photovoltaic applications are reviewed and preliminary economic evaluations of those projects are given. It is concluded that potential widespread utilization of photovoltaic energy technologies in Thailand appear to be limited to telecommunications applications. Nevertheless, utilization on household lighting in remote unelectrified rural areas may be commercially feasible and improvement in the overall system efficiency for a direct coupling solar pumping system may increase public organization activities on setting up the system for rural development in remote and politically-sensitive areas.

INTRODUCTION

Energy is recognized as an essential element for human needs, economic and security of a nation. As a consequence of a national development program in the past decade, Thailand energy consumption increased over two fold.

Electricity is generally regarded as high-grade energy and as a matter of fact electricity is justified as one of the most important basic infrastructures for rural development. Benefits derived from rural electrification are many[1], for example:

Reduction in the cost of energy for lighting

Fuel saving will be attained for rural people to use electrical appliances instead of oil-based equipment as a result of better energy conversion.

Education

Electrification will greatly enhance the opportunity for rural people by receiving informal education information from radio broadcasting, television and audio-visual apparatus.

Increase in labour productivity

Usage of electrical equipment will provide better conversion efficiency and in turn, more labour saving will be attained. During a non-daylight period, the use of electric light will provide sufficient illumination for extra working period.

Social & Security

A higher living condition level and better environment will be attained as a result of electrification. In sensitive areas, electrification will boost the rural peoples feeling of not being neglected and of being taken care of equally.

Realizing the significance of the provision of electricity for improving rural development, the Government of Thailand has given a high priority for the rural electrification program since 1973. Expansion of transmission grids to rural unelectrified villages has been accelerated during the past decade. In 1974, there were about 17,000 electrified villages as compared with 34,500 villages in 1984. Nevertheless, there are still about 20,000 unelectrified villages out of 54,000 villages (total villages in the whole kingdom at present). These villages have less electricity demand and are more remote and therefore, cost of investment and transmission for provision of electricity to those unelectrified villages has risen tremendously and has caused a financial burden to the government.

In this respect, it may be logically sound to consider decentralized electricity generation systems utilizing locally available energy resources for electricity generation to serve the needs of electricity in rural remote areas where the introduction of these alternative technologies are feasible. To date, several rural electrification programs utilizing alternative energy technologies have been undertaken. Solar photovoltaic technology is among those which are considered to be promising and may be brought into practical use in the near future for rural electricity generation, especially in remote areas.

SOLAR ENERGY

Resource

Thailand is fortunate to have moderately high solar energy. According to several assessments on solar energy resources, it may be concluded that Thailand is exposed to an annual average daily global solar radiation of about 4.67 kWh/m^2 with seasonal variation about ± 20%.

As the country is situated near the equator, the amount of diffuse solar radiation is quite high, and is approximately 40% of the total solar radiation.

At present, measured data on solar radiation in the country can be obtained from about 28 measurement stations. It is noted that only one station is equipped with a normal pyrheliometer and the rest are equipped with pyranometers or sunshine duration meters.

Utilization Potential

The National Energy Administration (NEA) has estimated the annual potential on solar energy utilization as shown in Table 1. Overall potential was about 8% of the national energy consumption in 1984, nevertheless, utilization of solar energy in 1985 was estimated to be about 0.1% of the potential.

Table 1
Solar energy potential

End use	Potential	Utilization	Substituted source
Low temperature hot water for household uses	1.6	0.3 (thermal)	LPG/Electricity
Low temperature hot water for uses in hotels, hospitals, etc.	n.a.	1.4 (thermal)	LPG/Electricity
High temperature hot water for uses in industries	1 473	~0 (thermal)	Fuel oil
Distilled water	n.a.	0.002 (thermal)	Electricity
Water pumping	71	~0 (PV)	Diesel/Gasoline
Lighting	300	0.013 (PV)	Kerosene/Diesel
Hot air drying	n.a.	~0 (thermal)	Wood/Fuel oil/ Lignite
Communications	n.a.	0.1 GWh (PV)	Battery/Diesel

Note: unit in million litres of crude oil equivalent.

Photovoltaic Technology Applications

Even though photovoltaic systems are suitable for any application since they can generate electricity from sunlight, in general, the systems are considered to be more suitable for rather small energy consumption applications in remote areas where no direct tie-in to an electric utility grid is available or where the transportation of fuel for generating electricity is very expensive or impractical. Applications for possible utilization in remote areas under current situations are telecommunications, household lighting, water pumping, and village electrification. Details on system descriptions of these applications are given in Table 2.

Competitiveness of Solar Photovoltaic Technology

Most solar energy systems installed so far are for demonstration or social and security purposes except those for telecommunications. As a result, economic viability has been less emphasized. Nevertheless, for the sake of general economic comparisons among different types of technology applicable to potential applications as mentioned, comparision among energy production costs are estimated as shown in Table 3. As in real situations many variables may considerably differ from those assumed in the investigation, depending on site characteristics, environment, variation in system configuration and performance, etc., therefore, a further detailed economic study is required.

Table 2
Applications and system description of solar PV electricity

Applications	System description
Telecommunications	
– military use	5-10 Wp solar array mobile unit
– remote working office, health center, temporary construction camp, school for audio-visual teaching aid, public television, public telephone, etc.	30-60 Wp solar array stationary unit
– repeater station	1000-4000 Wp solar system
Household lighting	
– decentralized	10-35 Wp solar system at individual household
– centralized	150-500 Wp solar system for battery charging. Charged batteries are to be transported for use at individual household
Water pumping	
– micro irrigation	300 Wp directed coupling solar pumping system
– village water supply	700-4500 Wp directed coupling solar pumping system
Village electrification	30-60 kWp solar system for one remote rural village

Table 3
General energy production cost comparison

System	Tele-communications (฿/kWh)	Water pumping (฿/m^3)	Household lighting (฿/kWh)	Village electrification (฿/kWh)
PV	50–100	1–20	50–100	50–125
Hydro	–	–	–	0.5–11
Biogas	–	0.1–2	–	4–16
Gasifier	–	0.1–2	12	3–16
Diesel	–	0.1–10	110	3–8
Battery	1000	–	70	–
Oil lamp	–	–	0.5 (฿/h)	–

Note: 27 Baht (฿) = 1 US$.

ACTIVITIES AND EXPERIENCES

Utilization

Utilization of PV solar energy has been in existence since the early 1970's for telecommunication applications which are usually accepted as viable and economically sound.. Only recently other applications have been demonstrated and tested in order to gain experience, to become familiarised with photovoltaic technology and to obtain relevant information for utilization when investment on solar cell systems becomes attractive both economically and financially. More than 120 kWp of solar cell has been installed in the country for various applications, including research and development activities in higher educational institutes. Details on annual capacity of installed PV systems in the last eight years and their application fields are shown in Table 4 and Table 5, respectively[2].

Table 4
Annual capacity of installed PV systems

Year	Capacity (Wp)
1978	96
1979	723
1980	1 378
1981	4 427
1982	5 982
1983	8 462
1984	80 687
1985	18 561

Table 5
PV solar system applications

Applications	Capacity (Wp)	Percent
Telecommunications	98 508	81.98
Domestic lighting	7 305	6.07
Water pumping	7 034	5.84
Audio-visual aid	1 155	0.96
Navigation aid	450	0.38
R&D	4 011	3.33
Medical refrigeration	210	0.18
Unclassified	1 634	1.36
Total	120 307	100.00

Note: Total capacity as of 1985

Projects

Projects under implementation and related activities in Thailand were reviewed in this section according to applications.

Photovoltaic Cell Fabrication

Photovoltaic cell fabrication has been under research and development in university laboratories. The Semiconductor Device Research Laboratory (SDRL), Chulalongkorn University has reported that by using new fabrication techniques with simpler methods and lower production costs, the SDRL was able to produce a single crystal silicon solar cell with cell efficiency of 8.2% @60 mW/cm^2 with quality control yield of about 70-80% and with an estimate production cost of about 87 Baht/cell (2 inches in diameter), and also a polycrystalline silicon solar cell of the same size at a cell efficiency of about 5.2-6.0% @67-75 mW/cm^2.[3] These results are encouraging but further improvements are needed in the annealing, nickle plating, and encapsulation processes. It is also noted that these results are based on production of only 100 cells and therefore further development work is also needed for automation on several fabrication processes, e.g., chemical polishing, chemical cleaning, impurity diffusion, oxidization, photolithography, metallization, soldering, etc.

Solar PV Water Pumping for Water Supply Project

In 1984, The National Energy Administration (NEA) with support from the U.S. Agency for International Development (USAID) installed a 720 Wp direct coupling PV water pumping system at Ban Thayiam, Sakolnakorn Province, a rural remote village in the Northeast[4]. The system consists of eighteen 40 Wp PV panels, one 1 HP permanent magnet DC motor coupled with a screw pump, and one 10 m^3 water storage tank centrally located in the village with transmission pipe connection for five 1 m^3 tanks in the village. The system can pump water from one artesian well with the total dynamic head of about 28 m and deliver water for domestic uses totalling about 5-7 m^3/day.

Field evaluation of the system was undertaken throughout 1984. It was found that during the summer season about 5-6 m^3/day of water was obtained from the system and the maximum efficiency was only 1.5% at 450 W/m^2. However, during the cool season when the ambient temperature was low, the daily flow increased to 6-7 m^3/day and the maximum efficiency was 1.8% at 400 W/m^2.[5] Further system evaluation on simulation of system performance revealed that low system efficiency occurred because of subsystem mismatching as a result of employing a positive displacement pump without a maximum power point tracker.

A PV water pumping system for village water supply at Ban Thayiam has been monitored for technical performance as well as operation and maintenance expense. The system can deliver water at an average daily production of 5-7 m^3 with operation and maintenance expense of about 1.5% of the initial investment. With the capital investment of 279,450 Baht, the annual cost and unit water cost are computed to be 44,599 Baht and 20.4 Baht/m^3, respectively, as shown in Tables 6-7, together with a comparison to a diesel engine pump system.

It is noted that the corresponding costs of the diesel system of comparable capacity are only 22,287-23,745 Baht and 10.2-10.8 Baht/m^3, respectively. In order to compete with the diesel system, the unit cost of the solar panel should be reduced from the present 10 US$/Wp to less than 5 US$/Wp.

Table 6
Investment cost

System	Cost (฿)	Service life (year)	Note
PV			
– Array	210 195	20	720 Wp @ US$10/Wp
– Motor	9 450	10	Installed cost
– Pump	59 805	10	= US$585
TOTAL	279 450		
DIESEL			
– Engine	17 000	10	
– Pump	59 805	10	
TOTAL	76 805		

Table 7
Annual cost and water cost

System	Annual cost (฿)	Water cost (฿/m^3)
PV		
– investment	40 406	
– O & M	4 193	
TOTAL	44 599	20.4
DIESEL		
– investment	13 593	
– O & M	7 236	
– fuel	1 458–2 916	
TOTAL	22 287–23 745	10.2–10.8
Annual water pumped	2 190 m^3	

Village Rural Electrification Projects

Several rural electrification projects have been demonstrated in remote rural areas by various organizations with different project approaches.

Provincial Electricity Authority (PEA)

PEA is now at the stage of demonstrating its PV solar power plant project (for the first time) during 1986 with support from the Japanese Government. The project will consist of 3 solar power plants, serving electricity demand of remote rural villages as shown in Table 8.

Table 8
PEA solar power plants

Project no	Site	Capacity (kWp)	Distance from grid (km)
1	Ban Mae Ka Si, Lat Yao District, Nakornsawan (100 households)	60	55
2	Ban Wang Mi, Pak Thongchai District, Nakornratchasima (60 households)	30	24
3	Ban Den Mai Sung, Ban Tak District, Tak (100 households)	60	27

These systems aim at satisfying electricity demand for the whole village. The generated dc electric current will be transformed to ac current in order to reduce losses in transmission line and still retain user flexibility on using available electrical appliances. It is considered to be a pilot project with the emphasis on obtaining realistic information for a further feasibility study and as operational experience for PEA officials. The estimated cost of the whole project was about 60.15 million Baht, of which 52.65 million Baht is foreign currency and has been sponsored by the Japanese Government.[6]

Most of the unelectrified villages are similar in that they are small in size with populations less than or about 400. Since this is the case, technical and investment information on Ban Wang Mi will be used. Unit production cost of electricity will be calculated according to a life cycle analysis. Factors assumed to be important are as follows:

- Service life of the solar panel, inverter and other electrical apparatus and battery are 20, 10, and 5 years, respectively;
- Electricity demand is about 0.84 kWh/day per household; and
- Operation and maintenance costs, are almost negligible and only the cost of civil work and electricity transmission lines are taken into account.

For the initial investment of 11.97 million Baht, as shown in Table 9, unit electricity production cost is calculated to be about 126 Baht/kWh with a discount rate of 12% and annual electricity demand of 18,396 kWh.

Table 9
Investment data on village electrification

Items	Cost (million Baht)
1. Solar power plant equipment	10.67
1.1 solar panels (30 kWp)	
1.2 batteries	
1.3 inverter (20 kW)	
2. Control room	0.52
3. Foundation	0.06
4. Residence	0.16
5. Distribution system	0.12
6. Other	0.44
Total	11.97
Capital annual cost	2.3098
O & M [1%* (2+3+4)+4%* (5)]	0.0122
Total annual cost	2.322
Electricity demand, kWh/y	18 396
Unit electricity cost, Baht/kWh	126

Energy Industry Development Office (EIDO)

EIDO set up several projects in various rural areas during 1983-1985, e.g.,

1. PV solar systems with a total capacity of 1,000 Wp to serve the need of lighting only at Ban Hai Song, Chiengrai Province. Arrays of 3-5 panels were installed at different locations in the village and each array was designed to be able to supply electricity for household lighting for 4 hours per day. Existing problems are due to the poor service life of the battery, the high rate of fluorescent lamp replacement, and an insufficient voltage level for households at the end of the electricity transmission lines.

2. PV solar systems with a capacity of approximately 350 Wp at eight remote rural villages. Lighting generated was for public gathering places and street lighting.

3. A 420 Wp solar system for 10 villages for battery charging. This system is designed to provide sufficient electricity to charge about 1-2 discharged batteries within 1 or 2 days. After that period, the charged batteries will be replaced by new discharged batteries on a rotation basis. This approach has been implemented by the EIDO lately and it is apparent that the EIDO considered this approach more suitable and versatile than those aforementioned.

National Energy Administration (NEA)

NEA has been engaged in PV systems for lighting applications during the past couple of years in a limited scope and for demonstration purposes only. Several small systems ranging from 30 Wp to 280 Wp have been demonstrated for lighting in rural areas, e.g. schools, military camp, rural households, and sight-seeing places.

Recently, NEA set up a rural household electrification program in order to make a rural energy demand assessment in the household sector. The information revealed that for unelectrified village, lighting is made possible mostly by oil-lamps with kerosene as a major source of fuel. However, the lighting efficiency of these lamps is very poor and kerosene is generally more expensive here than that available in urban areas due to the difficulty in transportation and therefore, the introduction of solar photovoltaic technology for lighting application in these areas seems to be appropriate. However, the capital investment is too formidable for the rural villager to afford. In this respect, NEA plans to design a system of about 10 Wp in order to reduce the initial capital investment but still provide lighting illumination equal to more than that of the oil-lamps. To cope with problems on short battery service life, the system would be equipped with a battery controller and a maintenance free and low self-discharge battery even though there will be an increase in the capital cost.

This project will be considerably different in the conceptual approach from those aforementioned as the project objective emphasizes evaluating user acceptance and marketing possibilities in the near future. It is planned that by providing the incentive of a low interest rate and a long term payback period, a rural villager can own a system on a rental basis with a monthly fee of about the expense of fuel for lighting needs. The program is planned to start in the late 1986 upon receiving the permission for trial marketing.

General economic assessment has been investigated for the NEA and EIDO systems for lighting application with a given requirement that a rural household normally requires lighting 4 hours/day with fluorescent lamps of 5-20 Watt capacity. It is noted that the illumination quality of lighting from a PV system is much higher than that of oil lamps, therefore unit production cost will be given in terms of Baht/h and Baht/lumen per hour in order to compare it with oil lamps.

Some key assumptions are as follows:

- service life of solar panels and an electrical controller are 20 and 10 years, respectively;
- service life of a lead-calcium or maintenance free type battery is 5 years with an efficiency (including all loses) of 80%;
- service life of a car battery is only 2 years with an efficiency of 60% including standby loss;
- service life of a fluorescent lamp is 1 year; and
- electric energy supplied from a solar panel is 3.75 kWh/day per kWp.

With a capital investment of 189 Baht/Wp for a solar panel and 2,000 Baht or 700 Baht for each unit of 50 AH maintenance free or car battery respectively, the unit production costs of a system of 10-35 Wp varied from 0.73 to 1.29 Baht/h or 0.00103 to 0.0021 Baht/lumen per hour for a system with maintenance free battery, and 1.19 Baht/h or 0.0025 Baht/lumen per hour for a system with a car battery as shown in Table 10.

Communications

Photovoltaic applications in communications activities such as radio communications, warning lights, and audio visual aids has been generally accepted as economically viable and is the first application which has been introduced to Thailand. Highlights on this application are as follows:

Table 10
Unit production cost for lighting applications

Items	Baht/h	Baht/lumen per hour
1. 10 Wp system with 35 AH maintenance free battery and 10 W lamp (2 h/day) and 5W lamp (2 h/day)	0.73	2.1×10^{-3}
2. 35 Wp system with 50 AH maintenance free battery and 20 W lamp (3 h/day) and 10W lamp (4 h/day).	1.29	1.03×10^{-3}
3. 35 Wp system with 50 AH car battery and 20 W lamp (3 h/day) and 10 W lamp (1 h/day)	1.19	2.50×10^{-3}
4. 100 AH car battery with 20 W lamp (3 h/day) and 10 W lamp (1-3 h/day) (charging cost 25 B/cycle, 48 cycle/year)	1.32	1.05×10^{-3}
5. Oil lamp (4 h/day) (3 units)	0.49	10.8×10^{-3}

1. Since 1979, photovoltaic systems have been used for long distance radio communications for the Foundation on Medical Volunteers. More than 160 units of the system with a capacity of 8-36 Wp have been installed at rural medical centers.

2. The Telephone Organization of Thailand (TOT) has equipped repeater stations in remote areas with photovoltaic systems. Systems of 1 280-3 968 Wp were installed at 52 stations during 1984-1985.

3. The EIDO has set up PV solar systems to energize television sets for about 25 rural villages. Each unit has a 35 Wp and 40 AH automotive battery with a charge controller and a television set.

4. The NEA has a demonstration project of 245 Wp audio visual aids at remote historical places. A similar system has been installed at the NEA research station with support from the New Energy Development Organization of Japan. This system, with a capacity of 350 Wp, is equipped with necessary monitoring instruments.

5. The Electricity Generating Authority of Thailand (EGAT) has installed several solar system units for warning lights at its power plant sites.

For telecommunications applications, a large number of solar systems of a capacity ranging from 5-3 968 Wp have been installed. Economic conditions depend largely on load demand and energy systems with which to be compared.

The electricity production cost of solar systems for telecommunications applications is considered to be similar to those systems for lighting application. Therefore, it appears to be attractive when compared with dry battery (electricity production cost of a 1.5 V and 3 AH dry battery is about 1 000 Baht/kWh).

PROBLEMS AND CONSTRAINTS

Information gathered by various organizations on existing problems and constraints for solar systems under implementation reveal that the operation and maintenance are only minor problems. Most systems are almost maintenance free and can be handled easily by rural people. The major obstacles for widespread utilization are the capital investment of the solar panels and its associated equipment, e.g. battery, inverter, dc motor, a maximum power point tracker. High capital investment prevents commercialization as rural people can not afford to own a solar system.

Other problems include improper system usage as many think that a solar system can provide free and unlimited amounts of energy and therefore they tend to use available electrical appliances with the system until it can not cope with the extra demand. This will result in system failure from the user's viewpoint.

Insufficient design consideration is another problem. A system with long electricity line will result in higher electricity loss and undesired voltage level.

As a result of the self discharge rate of battery which increases with service time until the energy is more than the system can supply, the battery at this stage will not be in a good working condition Some solar systems with a car battery were abandoned instead of having the battery replaced.

Most organizations appear to have constraints on carrying out a monitoring program on technical performance of a solar system under implementation, due to the lack of monitoring equipment, technical staff with sufficient background in energy technology, and limited budget for a monitoring program.

CONCLUSIONS

Widespread utilization of solar PV energy technologies in Thailand is still limited to those of telecommunications applications due to the heavy initial investment of a solar system and the generally unattractive electricity production cost when compared to existing conventional energy technologies.

Utilization for household lighting applications for a remote unelectrified rural household may be commercially feasible provided attractive incentives are given. System cost reduction will also be a key factor for market viability.

Improvement in overall system efficiency for a direct coupling solar water pumping system may increase public organization activities on setting up a stand alone water pumping system for rural development in remote and politically-sensitive rural areas.

Production of electricity from a solar system for the entire village electrification or for grid connection is unlikely to be feasible under the current situation and even in the near future unless drastic cost reduction for a solar system has been achieved.

Activities in research and development, field tests for system performance and feasibility assessments will be continued as it is recognized that solar energy will be a potential energy resource for exploitation in the future.

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