Feasibility Study of a Small-Scale Grid-Connected Solar Parabolic Biomass Hybrid Power Plant in Thailand

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Abstract

This paper focuses on the feasibility of a relatively new concept of the combination of a solar parabolic trough with a biomass backup system. The study concentrates on the feasibility of this concept in Thailand implemented on a small-scale grid-connected power plant.

1. Introduction

At present time, renewable energy technologies start to be well known. As a consequence, research and development have to explore new paths to improve their efficiencies, their competitiveness, and therefore to enlarge their development worldwide. However, before developing new concepts, their potential has to be demonstrated, in order to concentrate efforts on the more interesting ones. This project focuses on the feasibility of a relatively new concept. The study concentrates on the feasibility of this concept in Thailand implemented on a small-scale grid-connected power plant. The development of this project can roughly be divided into two steps: collection of relevant information and data, creation and development of a simulation tool using FORTRAN programming, and analysis and presentation of the results. First, the choice of a small-scale grid-connected solar parabolic biomass hybrid power plant is justified. In a second part, the simulation tool developed is described and it includes a more detailed characterization of the concept and the tools used to evaluate the feasibility of the power plant.

2. Small-Scale Grid-Connected Solar Parabolic Biomass Hybrid Power Plant in Thailand

The actual need for Thailand to install new power plants is to be more independent from the country producers of conventional fuels and consequently from the international situation. Furthermore, 70% of its electricity production is based on natural gas, and the domestic reserves are expected to be depleted within two decades. Finally, the electricity consumption has reached 106,138 GWh in 2003 with a growth rate of 7.1%. The latter is expected to carry on increasing at that rate of around 7% per year [1].

2.1 Grid-connected power plant

Currently, 99% of the 68,000 Thai villages are connected to the national grid and within few years, the remaining should be connected or should have a stand-alone power generation system [2]. So it is not very interesting to develop new concepts for non-grid-connected villages. Besides, a grid-connected system presents many advantages comparing to a stand-alone one. The grid connection can help in increasing the viability and the performance of such a system. In case of maintenance and operating problems, energy resource depletion, unexpected electricity demand, or undersized power plant after some years of operation comparing to the demand, electricity can be supplied to the community by the national grid as if it was only supplied by the system. The surplus of electricity generated due to an oversize, an unexpected low consumption of electricity or a constant load design, can be sell to the grid. A bigger installation can also be envisaged in order to reduce the initial costs of the plant per kWh and to increase the benefits by selling electricity to the distribution companies. Furthermore, this provides more options to design the power plant. The latter could be oversized (in the case of a design over the entire useful life), be designed to meet the maximum peak demand or the average peak demand, and have a constant output or not.

Finally, a grid-connected system enables us not to take into account the option of a possible thermal storage for the solar parabolic trough by using the grid as a battery. Indeed, with both a backup system and a grid connection, it is a good assumption that a storage system would be useless, and that the gain in efficiency would not be interesting as compared to the decrease of the economic performance. The problem of the degradation of the heat storage materials will also not have to be faced.

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2.2 Small-scale power plant

The main issue of small-scale systems is that the installation, the components and the maintenance costs are more expensive if they are put at the same level as of a usual power plant. Moreover, the operation and maintenance, and the training of the persons in charge are much more difficult and thus more expensive with a possible problem in the operation of the system.

Eventually, the size of most the existing solar parabolic trough power plants is superior to 14 MWe and the latter are not widespread. So the experience in solar parabolic trough is not as strong as in photovoltaic, biomass, etc. But the latter drawback is balanced by the higher efficiency of this technology comparing to photovoltaic and by the challenge in attempting to develop new concepts. Fortunately, there are many good reasons to develop small-scale power plants in Thailand. The main reason comes from a change of policy of the government. Indeed, the latter has decided to focus its attention on three points [3,4]: First, the promotion of domestic renewable energy resources, second the decentralization of the power generation and the increase of the role of the private sector in electricity generation.

From all these reasons, a second landmark in the Energy Supply Industry (ESI) occurred in 2002 with the Very Small Renewable Energy Power Producer (VSPP) legislation [5,6].

A VSPP is defined as a generator of the private sector, state agencies, state-owned enterprises or general public, with its own generating unit, whose power generating process utilizes renewable energy sources, agricultural and industrial wastes and residues, or by-product steam. It sells no more than 1 MW of electrical power to a distribution utility. With these recent regulations, it has become interesting and challenging to install small-scale power plants because the previous disadvantages are balanced and electricity producers face a new market.

2.3 Hybrid power plant

To suit the regulations of the VSPPs, we have to concentrate on the renewable energies, which could be competitive in the market of the small-scale grid-connected power plants. Moreover, the concept of a hybrid power plant will be introduced to increase the reliability of the system. Indeed, renewable energies are very sensible to unstable factors (like weather, seasons, luminosity, human factor, etc). Therefore, a combination of two different renewable energy sources would enable to avoid interruption in the power generation, and to increase the independence of the plant regarding to the grid. Among the different options available, the hydro energy option will not be taken into account because all the experience accumulated has shown that micro-hydro resource is self-reliable and relatively stable. Concerning wind energy, good wind areas are not widespread in Thailand and their potential is even limited. So, excluding geothermal which is also site-specific, it remains only solar and biomass energy sources, which have a good potential all over Thailand.

Solar energy

A project carried out by the Department of Energy Development and Promotion (DEDP) and Silpakorn University in 1999 set up a solar energy potential mapping in Thailand from satellite and ground based stations [7]. This study reveals that Thailand has a good potential for exploiting solar energy with an average total solar radiation of 18.2 MJ/m^2.day. Indeed, in April and May, all the country receives a peak solar radiation, that is to say between 20 and 24 MJ/m^2.day.

Solar energy can be collected either by solar collectors to get thermal energy or by photovoltaic (PV) systems to get electricity. Concerning solar thermal energy, around 50,000 m^2 of solar collector surface areas have been already installed and an annual average increase of 2,500 m^2 is expected. The main applications in Thailand are water heating and food drying. Regarding the PV technology for power generation, approximately, 6 MW of stand-alone and grid-connected systems have been installed. In 2006, 36 MW extra PV systems are planned to be installed. Most of the systems are solar home systems, solar cell battery charging stations, PV pumping, hybrid PV systems for power generation in national parks and wildlife sanctuaries, rooftop PV systems and PV grid supports [8,9].

Biomass energy

Biomass is one of the most important sources of renewable energy in Thailand. From a recent study evaluating the biomass resource in Thailand, many potential sources were identified such as agricultural and wood residues, woodfuels, new plantations, waste water from livestock farms and industries, and municipal solid wastes. Moreover, the choice of a small generation unit is one of the characteristics of electricity production from biomass. Indeed, it is preferable to get biomass from a limited number of sources located in a limited area, thus avoiding a too complex biomass gathering organization and additional commercial, transport and storage costs.

To simplify our study, we will concentrate on agricultural residues. As a matter of fact, the wood sector is characterized with high competitive uses of its raw materials and residues. Wood residues and woodfuels are already widely used as a primary source of energy in the rural area for cooking. So, even if the efficiency of the traditional boilers is not very high, this source of biomass is already used and it is better to concentrate on unused biomass resources, which have not yet an economic value. The collection process is also quite difficult and their size is various.

Furthermore, Thailand is now facing a problem of depletion of its wood resource by an uncontrolled deforestation. However, the development of rubber plantations will provide a consistent source of biomass. The residues of the wood industry have a big potential for electricity generation through cogeneration power plant but their continuous production does not require a hybrid power plant.

Concerning wastewater from pig farms and food processing industries, the technology (biogas system using Upflow Anaerobic Sludge Blanket (USBA) and fixed film technology) is substantially established and does not need hybridization with another source of energy.

Municipal solid waste solution is dismissed because in rural areas, the population concentration may not be enough to produce a potential source of energy. Besides, the calorific value of municipal solid waste would not be as high as in urban areas. The potential hazardous of the waste will lead to a very high cost regarding the installations required, the operation of the plant and especially the small size of the plant.

Finally, it remains the option of the agricultural residues. The latter are very attractive because they have at the present moment mostly no use in Thailand, and the quantities available are high. Among agricultural residues, the distinction between crop residues and animal slurries has to be made. Our study will concentrate on agricultural residues from crop because inversely to crop residues, animal slurries offer a significant constant supply of fuel (especially in industrial breeding). So, this resource does not require a hybridization to be more viable and has also to be studied with a high focus with environmental aspects, such as pollution of soil, of groundwater, etc. In the following sections, agricultural residues will refer to residues from crop production.

Agricultural sector is the base of Thailand's economy and accounts for about 60% of the labor forces. The country is the world's second largest exporter of rice, and a major producer of cassava, sugar cane, palm, coconut and livestock. According to the Estimation of Agricultural Residues Potential (2001), out of a production of 102.5 million tons of sugar cane, paddy, oil palm, coconut, cassava, maize, groundnut, cotton, soybean and sorghum, 66 million tons of residues were generated. 15.5 million tons were used as fuel for energy production and small amount for other purposes. So about 44 million tons of extra agricultural residues were unused. It represents a theoretical potential of 612.9 PJ (Pica joule) of energy.

This potentiality for electricity generation and the actual uselessness of agricultural residues comparing to the other sources of biomass make that there is no other need to justify this choice even if the technology and the experience about such a fuel are not established.

The procedure to evaluate an agricultural residue for electricity generation has to include the following components:

- Description of the generation of the residue,
- Sites of generation (location, ownership, density, size, etc),
- Seasonal availability
- Collection process of the residue
- Actual use and the possible competing uses (energy use, other uses with either economic value or no economic value)
- Fuel characteristics of the residue
- Conversion technologies available
- Market outlook
- Conclusion

This evaluation has to be carried out in order to assure a stable and viable environment for the biomass backup system. An environmental analysis could also be included. The success of biomass power generation systems will depend if the notion of environment sustainability is taken into account or not.

Besides, the evaluation of the real potential may not be right if no study of the technologies commercially available to use these residues for electricity generation is done.

Unfortunately, no evaluation of all the agricultural residues in Thailand is available. This lack of relevant documentation and data has to be filled to ensure the successful development of a biomass backup system based on agricultural residues [9,10,11,12].

3. Simulation Tool

The simulation tool used is a simple FORTRAN program to evaluate roughly a solar biomass power plant from a technical and economic point of view.

There are two options for the design of a hybrid power plant. The latter can either have one single Power Conversion Unit (PCU) or two PCUs. Having two different PCUs is an attractive idea because we can use the more adapted PCU technology to the solar trough and the biomass backup system. The connection between the solar trough or the backup system and its PCU is less complex than if we have to connect the two systems with a single PCU (Figure 1). The total efficiency is then better than for a single PCU (Figure 2).

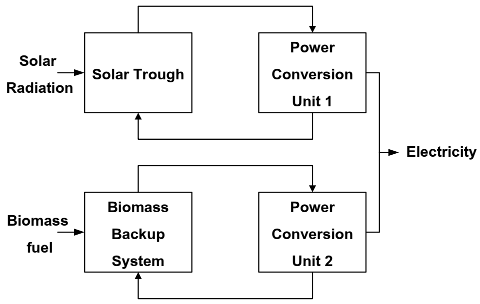

Figure 1: Model of a hybrid power plant with two PCUs

However, the main advantage of this option is balanced by the strong increase in costs due to the need of two PCUs. Moreover, the capacity factor of a single PCU, which could be defined as the amount of energy a facility generates in one year.

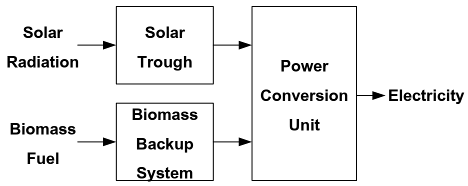

Figure 2: Model of a hybrid power plant with a single PCU

To model the solar trough, the direct radiation incident on the solar trough, since the diffuse radiation can not be used (Figure 3). The output is the thermal energy transported by the heat transfer fluid at the end of the solar trough. The model takes into account the main factors, which affect the conversion of the incident radiation into heat [12].

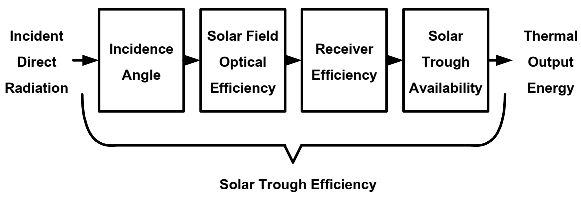

Figure 3: Solar parabolic trough model

The model of the biomass backup system is based on a boiler, a direct-fired biomass system, which is quite simple to design and the most commonly used (Figure 4). The input energy is the energy of the biomass fuel supplied based on its High Heating Value (HHV), and the output is the thermal energy transported by the heat transfer fluid towards the PCU.

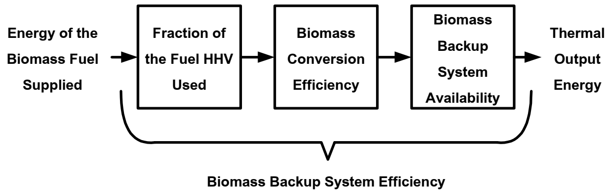

Figure 4: Biomass backup system model

The input of the PCU model is the sum of the thermal energy provided by the solar trough and by the biomass backup system. The output is the electricity generated by the hybrid solar biomass power plant (Figure 5).

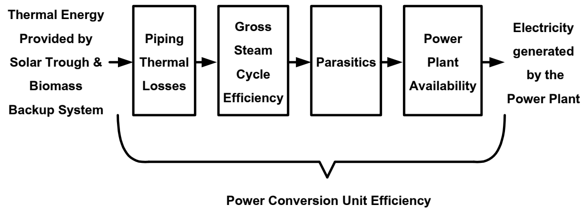

Figure 5: Power Conversion Unit Model

4. Results

The table below sums up the cases of different designs of a power plant of 800 kW, assuming an effective interest rate of 8 %, a useful life of 25 years and a scaling factor of 0.7.

Table 1: Comparison of Different Designs for the Small-Scale Hybrid Power Plant

	Solar Biomass Hybrid Power Plant				Solar Parabolic Power Plant	Biomass Power Plant
	General	Case 1	Case2	Case3		
Solar Trough Area (m^2)	9984.8	7987.8	9984.8	7987.8	9984.8	0.0
Annual Amount of Biomass Required (ton/year)	6691.7	7026.3	2851.4	4041.1	0.0	8364.7
Annual Efficiency (%)	16.66	16.88	15.74	16.40	12.34	17.74
Annual Electricity Generation (kWh/year)	7,008,000	7,008,000	3,790,497	4,506,970	1,401,604	700,800
Annual CO_2 Savings ($tonCO_2$/year)	5256	5256	2843	3380	1051	5256
Power Plant Capacity Factor (%)	100.00	100.00	54.09	64.31	20.00	100.00
Average Solar Fraction (%)	20.00	16.00	36.98	24.88	100.00	0.00
Average Biomass Fraction (%)	80.00	84.00	63.02	75.12	0.00	100.00
	ES and No CO_2 RI					
Initial Capital Cost (Mbaht)	427.01	388.83	395.88	357.70	346.02	163.02
COE (baht/kWh)	6.78	6.24	11.17	8.65	25.52	3.00
Average Electricity Purchase Tariff (baht/kWh)	3.80	3.51	5.01	4.14	9.50	2.37
NPV (Mbaht)	-222.89	-203.89	-249.44	-216.88	-239.65	-47.22
IRR (%)	0.9	0.8	-1.1	-0.6	-2.4	4.4
	ES and CO_2 RI					
Initial Capital Cost (Mbaht)	427.01	388.83	395.88	357.70	346.02	163.02
COE (baht/kWh)	5.93	5.39	10.33	7.81	24.67	2.16
Average Electricity Purchase Tariff (baht/kWh)	3.80	3.51	5.01	4.14	9.50	2.37
NPV (Mbaht)	-159.77	-140.77	-215.30	-176.29	-227.03	15.89
IRR (%)	3.2	3.4	0.5	1.4	-1.6	9.1

The study show that the higher part in electricity generation the biomass backup system takes, the more viable is the power plant. This is explained by the fact that the cost of electricity for a biomass power plant is only 3.0 baht/kWh whereas it is 24.7 baht/kWh for a solar parabolic power plant. It can be concluded that on a small scale, without different purchase tariffs (depending on peak/partial peak/off peak load), it is more interesting on an economical point of view, to focus on a design, which has the highest capacity factor. It means that the higher the electricity generation is, the more viable is the power plant.

Finally, that the use of a biomass backup system can improve significantly the viability of the solar trough power plant, reducing approximately the cost of electricity from 25.5 baht/kWh to 6.8 baht/kWh. Nevertheless, we have to admit that without strong support from the government, it is useless to expect the development of small-scale solar biomass power plants in the short or medium term, in Thailand. This is principally due to both the high initial capital cost of the solar trough system and the low direct radiation content of the solar radiation in Thailand. Moreover, even if the CO_2 revenue income can improve significantly the viability of certain projects, the results of the study are too uncompetitive to be affected very much by the CO_2 incentive.

5. Conclusion

The author first wants to underline the fact that this paper has to be considered as a rough study in order to give a general idea of the feasibility of a small-scale grid-connected solar parabolic biomass power plant in Thailand. As a matter of fact, it would be a waste of time and money to do a very accurate technical and economic study if we do not know if the project has minimum chances to be feasible and viable. Nevertheless, in case of which the results of the feasibility study are positive, accurate technical, economic and environmental studies would have to be done to overcome technical, environmental, economic, financial, human and organizational issues.

6. Acknowledgement

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