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# Optimal electricity development by increasing solar resources in diesel-based micro grid of island society in Thailand

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ABSTRACT

Isolated grid diesel-based systems have been a basic electricity system in islands in developing countries. Nevertheless, the increasing diesel price and the higher cost of diesel transport to a long distance to the remote islands make the diesel-based systems unsustainable. This study analyzes the viability to increase solar photovoltaic (PV) resources in the existing diesel-based systems. The hybrid PV/diesel system is not only reducing the cost of electricity generation but also decreasing the harmful emissions from fossil fuels. This study uses net present cost (NPC) to evaluate the optimum PV/diesel system configurations for installation in isolated island in Thailand. The results of analyses show that the optimal case PV/diesel system can decrease COE from $0.429/kWh to $0.374/kWh when compared to the existing diesel-based system and can decrease emissions both carbon dioxide of 796.61 tons/yr and other gases of 21.47 tons/yr. The hybrid PV/diesel system also reduces diesel fuel consumption of 302,510 liters per year as a result from an optimal of 41% PV resource shares in this system.



## 1. Introduction

Electricity consumptions in Thailand from 2013 to 2035, is approximately forecast with annually increasing rate of 3.8% (IEA, 2013), that it will increase to 346,767 GWh in 2030 (EGAT, 2010). Historical electricity consumptions in Thailand is shown in Table 1. The electricity consumption per capita in Thailand in 2013 was 2536 kWh (DEDE, 2013). This consumption per capita is very high when compared to other Southeast Asian countries. For example, when compares to Malaysia's consumption according with economic growth base, Thailand's GDP per capita in 2011 was only half of Malaysia's (IEA, 2013) but electricity consumption per capita in Thailand is the same as of Malaysia's. The domestic power installation in 2013 was only 33,618 MW, however it is not to meet the higher electricity demand, Thailand needs to import electricity from Laos PDR, Malaysia. Therefore, Thailand is the net import electricity in Southeast Asian countries. Electricity capacity, electricity demand, power plant efficiency, and national grid losses in Thailand are shown in Table 2.

The Ministry of Energy has come up with a policy to develop the renewable energy (RE) and setup the Alternative Energy Development Plan (AEDP) for period 2012–2021 (DEDE, 2012). The objective of AEDP Plan is to increase the portfolio of renewable energy to 25% in final energy consumption in 2021. The updated AEDP plan aims at increasing renewable electricity generation in Thailand to 13,924 MW by 2021. The AEDP plan is expected to be integrated higher renewable energy in electricity generation. However the updated AEDP in 2015 called AEDP 2015 (DEDE, 2015), is aiming to increase shares of renewable energy penetration in electricity generation in Thailand to 20%, which is equivalent to 19,635 MW by 2036, the new AEDP plan is expected to be integrated renewable energy in electricity generation. Power capacity will increase from 4279 MW in 2014 to 19,635 MW in 2036. Since Thailand is an agricultural-based country and high solar irradiation potential, Thailand set high targets of renewable electricity capacity for solar power (6000 MW), biomass (5570 MW), hydro power (3282 MW), wind power (3002 MW), biogas (600 MW), municipal solid waste (501 MW), and electricity from energy crops (680 MW). The details of distribution of renewable energy is shown in Table 3.

The electricity accessibility level in islands in Thailand is very low due to the difficulty of grid extensions, and the higher costs of grid accessibility in remote areas when compared to the whole areas in country with the rate of 99% electricity accessibility (IEA, 2013). In remote islands, electricity is mainly supplied by diesel generators. Though diesel systems have their distinctive advantages of electricity generation in remote areas, but higher diesel costs, especially at the uncertain demands and load fluctuation, and the costs of battery storage, and

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**Table 1**
Final energy consumptions by energy type in Thailand.
*Source:* DEDE (2013) and EGAT (2013).

| Final energy consumption (ktoe) | | | | | | Growth (%) | Shares of energy type (%) |
|---|---|---|---|---|---|---|---|
| | 2009 | 2010 | 2011 | 2012 | 2013 | 2013 | 2013 |
| Petroleum products | 31,661 | 32,096 | 33,078 | 34,881 | 35,948 | 3.1 | 47.8 |
| Electricity | 11,521 | 12,724 | 12,671 | 13,783 | 14,002 | 1.6 | 18.6 |
| Renewable energy | 4,134 | 4,534 | 13,138 | 12,976 | 13,978 | 7.7 | 18.6 |
| Coal & Its products | 7,493 | 8,240 | 7,190 | 6,582 | 5,947 | −9.6 | 7.9 |
| Natural gas | 3,568 | 3,769 | 4,485 | 5,094 | 5,339 | 4.8 | 7.1 |
| **Total** | **66,698** | **70,248** | **70,562** | **73,316** | **75,214** | **2.6** | **100** |

**Table 2**
Electricity generation, consumption and power system efficiencies and losses in Thailand.
*Source:* DEDE (2013).

| | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|
| Installed capacity (MW) | 30,607 | 31,485 | 31,773 | 33,177 | 33,618 |
| Peak power generation (MW) | 23,064 | 25,094 | 23,388 | 24,825 | 26,598 |
| Electricity power generation (GWh) | 148,390 | 159,518 | 155,986 | 168,178 | 169,593 |
| Electricity consumption (GWh) | 135,209 | 149,320 | 148,700 | 161,750 | 164,323 |
| Population (1000 person) | 63,525 | 63,878 | 64,076 | 64,457 | 64,786 |
| Electricity consumption per capita (kWh/person) | 2128 | 2338 | 2321 | 2509 | 2536 |
| Average thermal power efficiency (%) | 38.3 | 38.3 | 37.9 | 38.4 | 39.8 |
| National electricity grid loss (%) | 5.9 | 6.3 | 6.9 | 5.6 | 6.1 |

**Table 3**
Accumulated installed capacity of renewable energy in Thailand, MW.
*Source:* DEDE (2013).

| Renewable energy | Accumulated installed capacity | | | | | Growth rate |
|---|---|---|---|---|---|---|
| | 2009 | 2010 | 2011 | 2012 | 2013 | 2012–2013 |
| Solar | 37.0 | 48.6 | 78.7 | 376.7 | 823.5 | 118.6% |
| Wind | 5.1 | 5.6 | 7.3 | 111.7 | 222.7 | 99.4% |
| Small hydro | 55.7 | 58.9 | 95.7 | 101.8 | 108.8 | 6.9% |
| Biomass | 1618.1 | 1650.2 | 1790.2 | 1959.9 | 2320.8 | 18.4% |
| Biogas | 69.8 | 103.4 | 159.2 | 193.4 | 265.7 | 37.4% |
| MSW | 6.6 | 13.1 | 25.5 | 42.7 | 47.5 | 11.2% |
| Total | 1792.3 | 1879.8 | 2156.6 | 2786.2 | 3788.5 | 35.9% |

This installed capacity including off-grid power generation; MSW stands for Municipality Solid Waste.

with the transportation cost of diesel fuels to the islands, are also prohibitively to sustainable development. In Thailand, the application of renewable energy technologies (RETs) for islands has been increasing in recent years, but it is not very widespread. Therefore, the concept of PV–diesel hybrid electricity system is an alternative sustainable energy solution because it uses abundant solar resources combined with diesel fuels to create a kind of hybrid energy sources to provide electricity in islands.

PV/diesel hybrid electricity system is an effective sustainable energy development in many islands. It uses diesel with solar resources, so it can reduce air pollutant emissions. Thailand is located in the hot tropical zone. Geographical distribution of annual solar radiation map indicated that 45% of total areas of overall country receiving solar energy of 17–18 MJ/m$^2$/day, which can produce electricity 4.72–5.0 kWh/m$^2$/day (DEDE, 2010). With the abundance of solar resources PV farms have been already installed in Thailand with a capacity of 989.7 MW (in the first quarters of 2015). Thai government has promoted the small scale solar PV installations such as solar rooftops in the residential, and in the commercial buildings. In terms of hybrid PV/diesel system, or PV/Wind/diesel system, Thailand has already successful experiences of installation hybrid systems in some islands. The hybrid PV/diesel in Koh-jig island in Thailand was studied (Phuangpornpitak and Kumar, 2011), and the system in this island was installed. This island located in Chantaburi province on the eastern coast of Thailand. This hybrid PV/diesel installed with the battery storage; the system comprises of 7.5 kW PV arrays, 60 kW diesel generator capacity, and 60 units of battery capacity of 2100 Ah. The system is more cost-effective than the stand-alone diesel generation (the cost varied with $0.315–$0.526 per kWh), and significantly reduces pollutant emissions and noise problem from diesel generators. The study of economic feasibility of decentralized hybrid PV/diesel with the battery storage in Northern part of Nigeria and indicated that the COE varying between $0.348/kWh and $0.378/kWh (depending on the interest rates) which its cost was cheaper than the stand-alone diesel generation (the cost varying between $0.417/kWh and $0.423/kWh) (Adaramola et al., 2014b). The optimal sizing of hybrid wind/diesel/battery in isolated system in Portugal using Mixed-Integer Linear Programming formulation (MILP) (Malheiro et al., 2015). They found that wind/solar PV/diesel/batteries was the most cost effective options. The electricity cost in this system was $0.2499/kWh when compared to the standalone diesel generation system with its cost of $0.6256/kWh. With regard to the minimized cost and $CO_2$ emissions consideration, the study of the hybrid PV/diesel with the battery storage in a remote resident area shows that the hybrid system was more cost-effective than both diesel-only system. The share of renewable energy in optimal case was 27%, with 2.5 MW solar PV and 4.5 MW diesel generator installations (Shaahid and El-Amin, 2009). The hybrid PV/diesel with battery storage in isolated island in Malaysia with the varying of load demand consumptions, diesel prices and interest rates, and they found that at low interest rates of less than 3% would be a desirable solution for the hybrid PV/diesel with the battery storage over the diesel-only generation system, with regardless of any load sizes. The study found that when diesel price was $1.22/l or higher, the hybrid PV/diesel with battery storage was more feasible than the case of diesel-only system, in terms of COE consideration (Lau et al., 2015).