Techno-Economic and dynamic analysis of low velocity wind turbines for rural electrification in agricultural area of Ratchaburi Province, Thailand

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Abstract. This paper presents the analysis of potential wind speed of electrical power generating using for agriculture in Ratchaburi province, Thailand. The total area is 1,900 square kilometers. First of all, the agriculture electrical load (AEL) data was investigated from all farming districts in Ratchaburi. Subsequently, the load data was analyzed and classified by the load power and energy consumption at individual district. The wind turbine generator (WTG) at capacity rate of 200w, 500w, 1,000w, and 2,000w were adopted to implement for the AEL in each area at wind speed range of 3 to 6 m/s. This paper shows the approach based on the wind speed at individual district to determine the capacity of WTG using the capacitor factor (CF) and the cost of energy (COE) in baht per unit under different WTG value rates. Ten locations for wind station installations are practical investigated. Results show that for instance, the Damnoen Sa-duak (DN-04) one of WTG candidate site is identically significant for economic investment of installing rated WTG. The results of COE are important to determine whether a wind site is good or not.

1. Introduction
Generally, among various renewable energy resources, wind power energy is one of the most popular and promising energy resources in the whole world. With the specific wind turbine, the available electricity generated by a wind power generation system depends on mean wind speed (MWS), standard deviation of wind speed and location of installation [1]. The importance of utilizing the renewable energy system, wind turbine generator (WTG) has been attracted greatly in these days because the agriculture electrical load demand is need for the renewable energy resource and it has formulated as a national strategy for the development of renewable energy application and energy conservation measures. For this paper purpose, continues an effort to study more wind potential on individual distinct (10 districts) of Ratchaburi province in Thailand with optimal cost and number of WTG installation in area-base. Today’s wind turbines are state-of-the-art-of modern technology modular and very quick to install. Stand-alone power generation system is an important alternative source of electrical energy, find applications in location where convention generation is not practical. Consider, for instance, agriculture farm or ranches located far away from main power lines. It has been shown that a remote load has only to be a matter of a few kilometer away from a main power transmission line for a stand-alone wind
turbine generator to be cost-effective [2],[3] and cornerstone in the future green energy market [4],[5],[6].

This paper focuses on the agriculture electrical load (AEL) to determine the capacity of WTG under rated wind speed data recorded from area-base location in Ratchaburi province of Thailand. The cost of energy (COE), capacity factor (CF) and capital costs of WTG under different location are also determined. These parameters can be used to evaluate the performance of wind speed and wind turbine generator installation in each distinct of Ratchaburi province.

2. Methodology
In this paper, the economic analysis of the electrical power generating from low speed wind range about 3 to 6 m/s was investigated. There are the procedures of calculation as following, the investigation of wind speed data and AEL in area-base. Then, the numbers of WTG installation have calculated by Eq. 1 by the individual AEL, can be as express

\[
WTG_{RATED} = \left( \frac{Energy_{USED}}{Capacity_{hour}} \right) \times 1.25
\]

Where \(Energy_{USED}\) is the used energy in watt-hour unit, and \(capacity_{hour}\) is the ability of WTG. It can be generated the electrical energy (watt-hour) in period 8 hour/day and the capacity factor (CF) can be calculated by Eq.2

\[
CF = \frac{L_{avg} (kW)}{(kW_{inst})} = \frac{kWh_{gen} (year)}{(kW_{inst}) \times 8,760}
\]

Where \(L_{avg}(kW)\) is the average load, \(kW_{inst}\) is the power generating installation, \(kWh_{gen}\) is the electrical energy generating per year, and \(kW_{inst}\) is the electrical energy installation per year (hour).

The cost of energy [7] is free of detailed economic variables. The term COE is defined as the unit cost produce energy (in baht per kilowatt-hour) from WTG [8], and it can be expressed by Eq. 3

\[
COE = \frac{NPV(C_A)}{E_f} = \frac{C_t}{(8,760 \times n)} \times \left( \frac{1}{P_R C_F} \right) \times \left[ 1 + m \left( \frac{(1 + I)^n - 1}{I(1 + I)^n} \right) \right]
\]

Where \(C_t\) is the capital cost in baht, \(P_R\) is the power generating rate, \(C_F\) is the capacity factor, \(m\) is the average annual operation and maintenance cost in baht, \(I\) is the interest rate, and \(n\) is the lifetime of WTG.

3. Investigation of agriculture electrical load data
The Agriculture electrical load was investigated in Ratchaburi area by the collection of information outside a laboratory. The Ratchaburi is a province, which is consist of ten districts. From the AEL data, it can be classified device into 2 groups that are water pump into the farm and electrical lamp, fan etc. The total agriculture electrical load of each district is shown table 1.
Table 1 Amount of using Electric in area-base Agriculture Self-Reliance in Ratchaburi Province

| Area-base in Ratchaburi (10 districts) | Amount of using Electric in area-base Agriculture Self-Reliance in Ratchaburi Province |
|--------------------------------------|--------------------------------------------------------------------------------------|
|                                      | AEL in area-base, (kW) | Electrical energy in area-base (kWh) | Area-base for case study (m²) | Expected energy supplied for load (kWh/m²) | All agriculture area-base (Sq.km) | Expected energy supplied for all load (kWh) |
|--------------------------------------|------------------------|--------------------------------------|-----------------------------|---------------------------------------------|----------------------------------|-----------------------------------------------|
| Mueang Ratchaburi (M.-01)            | 1.026                  | 5.626                                | 3,600                       | 2.813                                       | 188.35                           | 331,149                                      |
| Wat Phae (WPB-02)                    | 1.865                  | 2.984                                | 6,400                       | 0.746                                       | 34.55                            | 16,108                                       |
| Damnoen Saduak (DN.-04)              | 5.222                  | 28.348                               | 3,600                       | 14.174                                      | 161.52                           | 1,430,879                                    |
| Pak Tho (PT.-08)                     | 2.707                  | 10.540                               | 14,400                      | 1.171                                       | 261.44                           | 191,338                                      |
| Photharam (PTR.-05)                  | 2.338                  | 28.056                               | 8,000                       | 5.611                                       | 227.41                           | 797,514                                      |
| Bang Phae (BPH.-03)                  | 4.476                  | 89.52                                | 12,800                      | 11.19                                       | 111.92                           | 782,707                                      |
| Ban Pong (BP.-06)                    | 2.707                  | 0.756                                | 9,600                       | 0.126                                       | 202.05                           | 15,911                                       |
| Chom Bueng (CH.B-07)                 | 1.227                  | 2.346                                | 4,800                       | 0.782                                       | 359.76                           | 175,833                                      |
| Ban KhaBK.-10                        | 1.624                  | 3.614                                | 8,000                       | 0.628                                       | 216.55                           | 84,994                                       |
| Suan PhuengSP-09                     | 1.937                  | 2.827                                | 16,000                      | 0.283                                       | 144.48                           | 25,555                                       |
|                                      |                        |                                      |                             |                                             | Total                            | 3,851,988                                     |

4. Wind turbine power model

A typical configuration of permanence magnet synchronous generator (PMSGs) bases wind energy conversion system consists of a generator side converter interconnected through an intermediate DC-link as shown in figure 1 which Given a plant size in terms of annual energy production, the COE can be minimized by choosing the optimum GRR [9].

**Figure1:** Typical configuration of wind energy conversion system for agriculture electrical load

In this paper, the 4 rate types of WTG such as 200w, 500w, 1,000w and 2,000w were studied. Result is shown in figure 2
Figures 2. Power and Wind Speed of wind turbine generator (PMSG) and practical wind speed test

Figure 2 shows the rated wind turbine generating are differently 4 class criteria. Rated WTG 2000w is the maximum power generator and 200w is the minimum power generator. Where the blue line is represented the maximum WTG at rated 2000w, considering speed range 3 to 6 m/s therefore at the 3 m/s is cut-in wind speed for starting up operating WTG point. The purple line, the green line and the red line are represented the rated WTG 1,000w, 500w and 200w respectively. Figure 2 (in the right hand side picture) shows the practical wind speed test in Damnoen Saduak (DN-04) site at the tower height of 8 meter. It can collect data at the average wind speed rage from 3 to 6 m/s.

5. Economic analysis of wind power generating

Form the Table 1 is the total agriculture electrical loads; it has obtained from the fieldwork. The AEL data is calculated by Eq.1 and it obtained the results that are the rated wind turbine generator and number installation. From these results, it can be evaluated the economic investment that is CF and COE.

For example, Damnoen Sa-duak district, it is found that a total agriculture electrical load is 1,632 kilowatt/sq.km and all electrical energy consumption is 8,858.75 kilowatt-hour/sq.km. And the total energy can be calculated from the total power at capacity WTG in 8 hour. The capital cost was estimated by market prices in Thailand. The CF of power wind generating is the ratio of its actual output over a period of time. So, the COE can be calculated from net present value (NPV) with consideration of the interest rate 12% and life time of WTG 20 years. Results are shown in Table 2 to 5.

| Wind Speed (m/s) | WTG 200w | Number wind Site (Station) | Total Power (Watt) | Total Energy (Whr) at 8hr. | Capital Cost* (Baht) | CF | COE** (baht/unit) |
|-----------------|----------|-----------------------------|-------------------|---------------------------|---------------------|----|------------------|
| 3               | 50       | 45                          | 2,250             | 18,000                    | 742,500             | 0.0833 | 38.0632           |
| 4               | 112      | 20                          | 2,240             | 17,920                    | 330,000             | 0.1867 | 7.5859            |
| 5               | 166      | 14                          | 2,324             | 18,592                    | 231,000             | 0.2767 | 3.4532            |
| 6               | 200      | 11                          | 2,200             | 17,600                    | 181,500             | 0.3333 | 2.3789            |

*included the all converter and battery system price.

**life time of WTG about 20 year and interest rate 12% per year
Tables 3 Indices performance of WTG vary from the variable wind speed (500w)

| Wind Speed (m/s) | WTG 500w | Number wind Site (Station) | Total Power (Watt) | Total Energy (Whr) 8hr. | Capital Cost* (Baht) | CF | COE** (baht/unit) |
|------------------|----------|-----------------------------|--------------------|------------------------|---------------------|----|------------------|
| 3                | 3        | 22                          | 2,200              | 17,600                 | 803,000             | 0.0667 | 39.4197         |
| 4                | 4        | 11                          | 2,255              | 18,040                 | 401,500             | 0.1367 | 9.3801          |
| 5                | 5        | 8                           | 2,400              | 19,200                 | 292,000             | 0.2000 | 4.3800          |
| 6                | 6        | 6                           | 2,370              | 18,960                 | 219,000             | 0.2633 | 2.5265          |

*included the all converter and battery system price.
**life time of WTG about 20 year and interest rate 12% per year

Tables 4 Indices performance of WTG vary from the variable wind speed (1,000w)

| Wind Speed (m/s) | WTG 1,000w | Number wind Site (Station) | Total Power (Watt) | Total Energy (Whr) 8hr. | Capital Cost* (Baht) | CF | COE** (baht/unit) |
|------------------|------------|-----------------------------|--------------------|------------------------|---------------------|----|------------------|
| 3                | 3          | 11                          | 2,200              | 17,600                 | 924,000             | 0.0667 | 45.3597         |
| 4                | 4          | 6                           | 2,400              | 19,200                 | 504,000             | 0.1333 | 22.6798         |
| 5                | 5          | 4                           | 2,400              | 19,200                 | 336,000             | 0.2000 | 15.1199         |
| 6                | 6          | 3                           | 2,100              | 16,800                 | 252,000             | 0.2333 | 12.9599         |

*included the all converter and battery system price.
**life time of WTG about 20 year and interest rate 12% per year

Tables 5 Indices performance of WTG vary from the variable wind speed (2,000w)

| Wind Speed (m/s) | WTG 2,000w | Number wind Site (Station) | Total Power (Watt) | Total Energy (Whr) 8hr. | Capital Cost* (Baht) | CF | COE** (baht/unit) |
|------------------|------------|-----------------------------|--------------------|------------------------|---------------------|----|------------------|
| 3                | 3          | 11                          | 2200               | 17,600                 | 1,100,000          | 0.0333 | 107.9992        |
| 4                | 4          | 5                           | 2500               | 20,000                 | 500,000            | 0.0738 | 22.0189         |
| 5                | 5          | 3                           | 2340               | 18,720                 | 300,000            | 0.1300 | 7.1005          |
| 6                | 6          | 2                           | 2200               | 17,600                 | 200,000            | 0.1833 | 3.5702          |

*included the all converter and battery system price.
**life time of WTG about 20 year and interest rate 12% per year

From the table 5, for instance, at wind speed of 3 m/s, rated wind turbine generator 2,000w can generate the total electrical power and the total electrical energy which is about 2,200w and 17,600 Whr respectively. This electrical energy value was evaluated by the capacity of WTG in period 8 hour per day (24hour). The number wind site, 11 sites is calculated from Eq.1 which considered in term of the used energy and capacity of WTG at wind power generating of variable wind speed. Both capacity factor (CF) and cost of energy (COE) can be calculated from Eq. 2 and Eq. 3 that are equal to 0.0333 and 107.9992 baht per unit respectively. From the results, the COE depended upon the CF value. When the CF value is increasing affect to the COE is decreasing value. That is relation of between the COE and CF is inverse function. It can conclude that it is suitable number of install WTGs and economic wind power generating.

6. Result
All agriculture electrical loads installed in the Damnoen Saduak distric are calculated by equation (1), (2), and (3). The results show the indices of capacity factor, cost of energy, wind power output (watt), electrical energy (watt-hour) and cost of investment per wind speeds (3 to 6m/s) as shown in figure 3

| Wind Speed (m/s) | WTG 1,000w | Number wind Site (Station) | Total Power (Watt) | Total Energy (Whr) 8hr. | Capital Cost* (Baht) | CF | COE** (baht/unit) |
|------------------|------------|-----------------------------|--------------------|------------------------|---------------------|----|------------------|
| 3                | 3          | 11                          | 2200               | 17,600                 | 924,000             | 0.0667 | 45.3597         |
| 4                | 4          | 6                           | 2,400              | 19,200                 | 336,000             | 0.2000 | 15.1199         |
| 5                | 5          | 4                           | 2,400              | 19,200                 | 252,000             | 0.2333 | 12.9599         |
| 6                | 6          | 3                           | 2,100              | 16,800                 | 229,000             | 0.2833 | 9.5799          |

*included the all converter and battery system price.
**life time of WTG about 20 year and interest rate 12% per year

From the table 5, for instance, at wind speed of 3 m/s, rated wind turbine generator 2,000w can generate the total electrical power and the total electrical energy which is about 2,200w and 17,600 Whr respectively. This electrical energy value was evaluated by the capacity of WTG in period 8 hour per day (24hour). The number wind site, 11 sites is calculated from Eq.1 which considered in term of the used energy and capacity of WTG at wind power generating of variable wind speed. Both capacity factor (CF) and cost of energy (COE) can be calculated from Eq. 2 and Eq. 3 that are equal to 0.0333 and 107.9992 baht per unit respectively. From the results, the COE depended upon the CF value. When the CF value is increasing affect to the COE is decreasing value. That is relation of between the COE and CF is inverse function. It can conclude that it is suitable number of install WTGs and economic wind power generating.

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Figures 3 Result of Performance Wind Turbine Generator and Cost of Energy at 3-6 m/s

(A-C-E-G) Performance Power Generating and Investment of WGT

(B-D-F-H) Economic of Electrical Energy Generating (baht per unit)

From figure 3 (in the left hand side) show the relationship of the cost of investment and the wind power generating rates at 200w, 500w, 1,000w and 2,000w (A-C-E-G) respectively. All results are considered at the wind speed range of 3 to 6 m/s. Where the dash-blue line represents the cost of
investment of WTGs install (baht). The dense red line represents the wind power generating output (watt) from variable wind speeds.

In the right hand side, figure 3 show the relations of the cost of energy in baht per unit and capacity of wind electrical energy generating at vary wind speed range of 3 to 6 m/s. The wind power generators were implemented at rate of 200w, 500w, 1,000w and 2,000w (B-D-F-H) respectively. Results show that with increasing of the wind speed, the cost of energy and amount of WTG installation significantly decrease.

7. Summary
In this paper, the analysis of the average wind speed potential in the west region of Thailand in Ratchaburi province, which consists of ten districts, is studied. The individual districts are investigated the AEL data for the evaluation of economic investment of WTG installation. The rated WTG have adopted to install at 200w, 500w, 1,000w and 2,000w respectively. From the AEL data, the average wind speed at individual district are determined the capacity of WTG using capacitor factor and cost of energy in baht per unit under different values of rated WTG. Results show that with increasing of the wind speed, the cost of energy and amount of WTG installation significantly decrease. These results can be the information for the government to decide the investment of WTG installation.

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