Validation of WRAM Wind Resource Map and Possibility to Utilise Wind Energy for Power Generation in Sri Lanka

Mahinsasa Narayana

Abstract: According to the present energy scenario in Sri Lanka, 65% of electricity is generated by fossil fuel. In this situation, utilisation of renewable energy for electricity generation is very important to mitigate economic and environmental issues. Wind energy has been identified as one of the promising renewable energy sources to generate electricity in Sri Lanka. When the quality and the accessibility of renewable energy resource data will be improved, the large-scale wind energy technologies can be developed in Sri Lanka by removing the resource information barrier. However, existing ground wind measurements are not sufficient to accomplish the comprehensive wind resource assessment in Sri Lanka. In this context, a high-resolution wind map has been developed by the WRAM. In this paper, WRAM wind map is validated by the WAsP prediction and cost of wind power generation in each part of Sri Lanka is discussed with comparing the existing power purchasing tariff system in the country.

Keywords: wind energy, wind map, wind resources grid, absorptive capacity, embedded power generations, and prime power generations

1. Introduction

Sri Lanka has a typical developing country power system with high demand growth rate and a total available generation capacity barely meeting the peak load. While the country has no indigenous fossil fuel resources, hydro resource is the only large-scale native primary source for conventional generation. Recently, wind energy has been identified as one of the promising energy option in Sri Lanka. However, the existing energy policies are not much helpful to promote the wind energy technologies in Sri Lanka. Quality and the accessibility wind resources data will enable private investors and public policy makers to assess the technical, economical and environmental potential for large-scale investments in wind technologies. In this context, National Renewable Energy Laboratory (NREL), USA has developed a 1km high-resolution wind map by using the Wind Resource Assessment Model (WRAM). Using a conservative assumption of 5MW per km², this assessment reveals windy lands in Sri Lanka support more than 24,000MW of potential installed capacity [1]. For more accurate wind resources assessment, detailed site-specific micrositing should be conducted by considering the existing transmission grid, accessibility, land availability, altitudes and topography.

2. Wind resource assessment model (WRAM) wind resource map in Sri Lanka

The WRAM is used to produce a wind resource map of gridded wind power density values with a 1-km² resolution and it was developed with powerful ArcInfo GIS software package. This model allows for a more consistent application of analysis techniques in a regional assessment, a more detailed analysis of the wind resource, and it produces high quality maps [2].

According to the WRAM wind resource map in Sri Lanka, there is nearly 5000km² of windy areas with good-to-excellent wind resource potential. The amount of land area of good-to-excellent wind resources at 50m is shown in table 1. National park, reserves, archaeological and cultural sites were excluded in this land coverage [1]. Hence, main object of this study is to verify the WRAM wind resource map in Sri Lanka by comparing the WAsP (Wind atlas software programme) predictions with measured wind data at few locations. Three locations namely Hambantota, Kalpitiya and Ambewela are selected for this comparison and wind power density of each location is determined by WRAM wind resource map.

Table 1. Good-to-excellent wind resources at 50m in Sri Lanka [1]

<table>
<thead>
<tr>
<th>Wind resources utility scale</th>
<th>Wind class</th>
<th>Wind power at 50m (W/m²)</th>
<th>Wind speed at 50m (m/s)</th>
<th>Land area km²</th>
<th>Lagoon area km²</th>
<th>Total area km²</th>
<th>Percentage of windy land</th>
<th>Total capacity installed MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>4</td>
<td>400-500</td>
<td>7.0-7.5</td>
<td>2,341</td>
<td>664</td>
<td>3,005</td>
<td>3.6%</td>
<td>15,000</td>
</tr>
<tr>
<td>Excellent</td>
<td>5</td>
<td>500-600</td>
<td>7.5-8.0</td>
<td>788</td>
<td>41</td>
<td>829</td>
<td>1.2%</td>
<td>4,150</td>
</tr>
<tr>
<td>Excellent</td>
<td>6</td>
<td>600-800</td>
<td>8.0-8.8</td>
<td>517</td>
<td>0</td>
<td>517</td>
<td>0.8%</td>
<td>2,600</td>
</tr>
<tr>
<td>Excellent</td>
<td>7</td>
<td>&gt;800</td>
<td>&gt;8.8</td>
<td>501</td>
<td>0</td>
<td>501</td>
<td>0.8%</td>
<td>2,500</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>4,147</td>
<td>705</td>
<td>4,852</td>
<td>6.4%</td>
<td>24,250</td>
</tr>
</tbody>
</table>

Figure 1. Wind atlases of selected regions in Sri Lanka

Figure 1. Wind atlases of selected regions in Sri Lanka
Table 2. Comparison of WAsP wind resources grid with the WRAM wind map

<table>
<thead>
<tr>
<th>Region</th>
<th>By WAsP wind resources grid</th>
<th>By WRAM map</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean wind speed (m/s)</td>
<td>Power density (W/m²)</td>
</tr>
<tr>
<td>Hambantota</td>
<td>5.74</td>
<td>5.04</td>
</tr>
<tr>
<td>Kalpitiya</td>
<td>8.77</td>
<td>7.8</td>
</tr>
<tr>
<td>Ambewela</td>
<td>6.96</td>
<td>1.46</td>
</tr>
</tbody>
</table>

3. WAsP prediction for selected locations in Sri Lanka

WAsP is a PC program for the prediction of the wind climates and power productions from wind turbines and wind farms. WAsP is developed at Risø National Laboratory, Denmark. The prediction is based on wind data measured at the stations in the same region. The program includes a complex terrain flow model and a roughness & sheltering obstacle model. To generate wind atlases for relevant locations measured wind data, topography and elevation details are required. Ceylon Electricity Board (CEB) of Sri Lanka has launched a program to collect the wind data in Sri Lanka and wind data were collected around 24 locations around the country. Topography and elevation details are inserted to WAsP model by 1:50,000 digitised survey maps. Measured wind data in 3 years period in Kjuwuwatta (E: 81° 06.3', N: 6° 08.7') for hambantota region, Narakkaliya (E: 79° 43.338', N: 8° 00.707') for Kalpitiya region and Ambewela (E: 80° 48.703', N: 6° 53.813') for Ambewela region are considered to generate the relevant wind atlases. Wind atlases of Hambantota, Kalpitiya and Ambewela regions are shown in figure 1. In this study, by using WAsP model, power density is determined and wind resources grid is generated for selected areas in Sri Lanka.

4. Comparison of WRAM and WAsP prediction

Due to the requirement of high quality measured wind data all over the country, development of a wind map by the WAsP model generated wind resources grid is a difficult task. Then existing WRAM wind map can be used for preliminary studies of wind technology development in the country. WAsP model can be used for accurate micrositing considering the site-specific details such as accessibility, grid transmission, topography and elevations. For verification, local area wind resources grid is generated by WAsP model and then it is compared with the WRAM wind map. Comparison results are presented in table 2. This comparison study shows that, WRAM wind resource map can be validated by the WAsP prediction.

5. Sri Lanka power generation system

Sri Lanka had state owned power generation plants. Mainly, these were the large hydro plants and few thermal plants. However, with the high demand growth rate, private power generations were promoted, due to lack of state funds for generation expansion. Mainly, private power generations are done by thermal power plants and few mini-hydro plants are being operated. Therefore, current power purchase tariff mechanism is adjusted to purchase thermal power from private power generations and it is based on least economic cost principle. Then this power purchase tariff system implies that, cost of energy is more important rather than the sources of generation. According to the power purchase mechanism in Sri Lanka, private power generation plants are categorised as prime power generations and embedded power generations. Embedded power generations are fed into the 400V or 33kV network. Prime power generations are the large power plants and commissioning according to the generation expansion plan in the country. Power purchase tariff rate of prime power generation is decided according to the power purchasing agreement with a private party for a certain power plant. This means prime power price is varied to plant to plant. Basically, private prime power generations are done by the thermal power generations and power purchase tariff rate is around 20.00Rs./kWh. Presently, The power purchase tariff rate of embedded power generation is around 5.80Rs./kWh. Mainly embedded power generations are consisted on renewable energy generations such as mini-hydro, wind and dendro (biomass). Preliminary studies of absorptive capacity for embedded generation found that if the necessary reinforcements are done to the network to eliminate the overload and voltage conflicts under normal and
abnormal system operation, 250MW of embedded generation could be accepted to the 2004 network across 9 specific generation locations [3]. When considering future development of the network find that the 2008 network will allow a maximum of 330MW to be connected. Similarly the 2012 model will allow 640MW and 2013 model 690MW. In these studies it was assumed that the output of all prime power generation would be reduced as the output of embedded generation is increased [3]. Approximately 120MW of embedded generations had been planned to connect to the network by the year of 2005 [5].

6. Cost of wind energy

Cost of energy depends on the capital cost of the plant, installation cost, commissioning cost, operation cost and maintenance cost. Cost of wind energy is highly site-specific as wind potential depends on the location. In this study, three locations are selected in Hambantota, Kalpitiya and Ambewela regions and the cost of wind power generation is calculated based on the predicted wind potential of each locations. Capacity of 3MW wind system (NEG MICON 600kW x 5No.) was installed in Hambantota region as a pilot plant. The total project cost was around Rs.280 million in the year 1997 (1US$=Rs.60 in year 1997) [4]. This was included the 10% GST and 3.4% custom duty. It is observed that the total operation & maintenance expenditure in the year 2000 excluding the servicing carried out by the turbine supplier is approximately 1% of the capital cost [4]. This cost is inclusive of the maintenance cost (replacement of brake pads), site staff and security expenditure [4].

On the other hand, present cost of the 600kW wind turbine in the world market is around US$450000. Transportation costs for the turbine may enter the calculation, if the site is very remote, though usually they will not exceed some US$15000. Then average price for large, modern wind farms is around US$1000 per kilowatt electrical power installed. However, to determine the cost of wind energy at the each selected locations in Sri Lanka, concerning the experience of the Hambantota pilot wind plant is very essential. Therefore, contemporary capital cost and installation cost of one 600kW wind turbine can be taken as Rs.96,000,000 (1US$=Rs.103 in year 2006) and annual operation & maintenance cost is taken as 1% of the capital. In view of Hambantota pilot wind farm, average price is around US$1555 per kilowatt electrical power installed.

By considering the installation of a 600kW wind turbine in the selected three locations at Hambantota, Kalpitiya and Ambewela regions, cost of wind energy is calculated by using the following financial model and results are shown in table 3. Annual energy production of a NEG-MICON-600kW wind turbine is calculated by considering the wind potential at the installed site and the wind turbine power curve (table 3). Wind potential for selected locations is determined by the WAsP prediction.

$$\text{COE} = \frac{C_{\text{ann,tot}}}{AEP} \quad --- (1)$$

Where: COE =Cost of energy (Rs./kWh), $C_{\text{ann,tot}}$ = Total annualised cost of the system (Rs.), AEP = Annual energy production (kWh)

Total annualised cost of the system ($C_{\text{ann,tot}}$) is the sum of the annualised capital cost ($C_{\text{ann,cap}}$), the annualised replacement cost ($C_{\text{arep}}$) and the annual operation and the maintenance cost.

$$C_{\text{ann,cap}} = C_{\text{cap}} \cdot \text{CRF}(i,R_{\text{proj}}) \quad --- (2)$$

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Estimated annual energy production of one NEG-MICON 600kW wind turbine</th>
<th>Capacity factor</th>
<th>Cost of wind energy (COE) (US$/1555/kW installed)</th>
<th>Cost of wind energy (COE) (US$/1000/kW installed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hambantota</td>
<td>06° 08.6'E 81° 09.4'</td>
<td>1104.038 MWh</td>
<td>21.0%</td>
<td>10.50 Rs./kWh</td>
<td>6.70 Rs./kWh</td>
</tr>
<tr>
<td>Hambantota- (Existing wind site)</td>
<td>06° 08.4'E 81° 06.6'</td>
<td>738.419 MWh</td>
<td>14.2%</td>
<td>15.45 Rs./kWh</td>
<td>10.00 Rs./kWh</td>
</tr>
<tr>
<td>Kalpitiya</td>
<td>08° 11.0'E 79° 42.5'</td>
<td>1551.527 MWh</td>
<td>29.5%</td>
<td>7.40 Rs./kWh</td>
<td>4.75 Rs./kWh</td>
</tr>
<tr>
<td>Ambewela</td>
<td>06° 53.5'E 80° 46.4'</td>
<td>2057.867 MWh</td>
<td>39.1%</td>
<td>5.60 Rs./kWh</td>
<td>3.60 Rs./kWh</td>
</tr>
</tbody>
</table>
Where; $C_{cap}$ = Initial capital cost (Rs.), CRF ($\cdot$) = Capital recovery factor, $i$ = Real interest rate, $R_{proj}$ = Project life time

The replacement cost is the cost of replacing a wind turbine at the end its lifetime. Annualised replacement cost of a system is the annualised value of the all the replacement cost occurring throughout the lifetime of the project.

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N-1} \quad ---(3)$$

where; $N$= Number of year, $i$ = Real interest rate

$$i = \frac{i' - f}{1 + f} \quad ---(4)$$

where; $i'$= nominal interest rate ($\approx$18%), $f$=annual inflation rate ($\approx$7%)

In this study, replacement cost is assumed as equal to the initial capital cost and real interest rate is taken as 10%. Lifetime of a wind turbine is assumed as 25 years and lifetime of the project is also taken as 25 years in this study. Therefore, annualised replacement cost is zero as lifetime of the project is equal to the lifetime of a wind turbine.

Mini-hydro and dendro are the other important non-conventional renewable energy sources in Sri Lanka. Mini-hydro is the cheapest source. However, it is highly site specific and limited. Cost of mini hydropower generation (<5MW capacity) in Sri Lanka is approximately 4.00Rs./kWh. Recently, dendropower is introduced for electricity generation and is identified as a socio-economically important power generation system in Sri Lanka. Cost of dendropower generation is around 7.00Rs./kWh (By existing technologies in Sri Lanka, 1.2kg of firewood is required to generate 1kWh).

Government tax and subsidiaries make considerable impact to the cost of energy. Energy policy & goal of the country is very important, when compare the different sources of power generation. In this study, foreign energy dependency, socio-economic factors and environmental issues are not considered for evaluating the cost of energy. However, when the long-term generations expansion of the country will be planned, these issues are very essential. Therefore, multi criteria should be analysed to select the suitable power generation systems for long-term generations expansion plan of the country.

7. Discussion

The WRAM wind resource map in Sri Lanka shows that, north, northwest and south have been identified as high wind potential regions and some parts of the central hill have superb wind potential. According to the wind resource assessments, considerable amount of wind power potential installed capacity is available in Sri Lanka. However, absorptive capacity of wind energy to the national network is limited due to the weaknesses of the network. At present, there is possibly to develop around 130MW wind power generation in Sri Lanka, if the necessary reinforcements are done to the network to eliminate overload and voltage conflicts under normal and abnormal system operation. Wind power generation can be further expanded, according to the future development of the network. Currently, existing power purchasing tariff mechanism of embedded power generations is adjusted only considering the mini-hydro power generations and then it is not promoted to utilise other renewables for power generation. However, this study shows that, cost of wind power generation is competitive with the other sources of renewable in Sri Lanka.

References