ABSTRACT

It is often advantageous to generate power with combinations of wind and ocean waves. In fact ocean waves, their generation, propagation, dissipation are directly related to wind velocity and its duration over the sea. In this paper an attempt has been made to demonstrate statistically to present some advantages with combined wind and ocean wave power generation. Even though many conceptual techniques and methods are possible to harness combined power generation, it is important to test feasibility of combined output as well as individual outputs mathematically. One of the major advantages of combined wind & wave power generation is to improve probability of continuous power supply (it minimises the interruptions and compensates power fluctuations with one another). Some of the major wave characteristics like wave height (H), Time period (T), Wave length (L) significantly influence wave power generation. Interestingly, these ocean waves are dependent on wind velocity over ocean. To establish, a relation, a simple mathematical model has been developed to test different sets of combinations with wind velocities and wave characteristics. Statistical analysis has been made to estimate individual as well as combined probability density functions for a range of power outputs. Probability density functions at certain combinations showed promising results and it indicates that, combined power generation improves probability of continuous power supply (i.e. it minimises one of the major criticisms for renewable sources of energy).

KEYWORDS

Wind Energy; Wave Power; Probability; Combined Power.

INTRODUCTION

Among many promising sources of alternative sources of energy, wind energy has many advantages over others because of its universal availability. Nevertheless, it cannot escape from one of the common criticisms for many renewable sources of energy - power supply fluctuations due to environmental changes. In order to develop means for constant power supply in the present investigation, a mathematical approach to investigate applicability of combined offshore wind energy and onshore wave energy plants has been discussed and some results were presented to illustrate application of the model. In offshore regions, due to vast undisturbed areas, wind velocities are much more predominant than on land. Temperatures and seasonal variations changes wind velocity at every instant. Since, wind power is directly proportional to cube of it’s velocity, even small changes in velocity make larger differences in final output from the wind power unit. Onshore wave energy plants depends on energy in waves at shore. Waves are generated in offshore mainly due to wind, travel and progress towards the shore and finally, depends on site conditions break and dissipate their energy at
It is of interest to investigate possibility of continuous supply of power from combined plants in order to minimise power fluctuations.

**MATHEMATICAL MODEL**

The basic aim of this paper is to illustrate and investigate mathematically the feasibility of integrated WAVE and WIND energy plants and to investigate how much increase in probability in total output energy and also see how far it will be able to improve probability of continuous supply of energy to meet demand with respect to variation in power. Mathematical model depends on input values of wind velocity at offshore and wave characteristics at wave energy plant. Linear wave theory has been adopted in this model to solve for wave length at wave energy unit (Count., B. 1980).

**BASIC ENERGY EQUATIONS**

\[
\text{Wind}_w = \frac{1}{2} \rho_w A V^3
\]

\[
\text{Wave}_w = \frac{1}{2} \rho_wgL^2 \left[ 4 \pi \frac{4 \pi T}{L} \right] \left( \text{L} \sinh \left( \frac{4 \pi L}{L} \right) \right)
\]

**ENERGY ESTIMATION AND DATA SETS**

From the above equations energy from offshore wind and energy from waves, based on wave characteristics at onshore can be estimated. Regarding data sets randomly generated data for offshore wind velocities and also similar sets of onshore wave characteristics data for 24 hours have been adopted to illustrate relative advantage of combined offshore wind energy and onshore wave energy plants. However, because of space limitations a limited set of data were used for this purpose. While combining and comparing energy from wind waves, wave energy is considered from energy from waves of one meter crest length and water depth of 30m, while wind energy is considered as energy from a wind generator or rotor area of 100 sq.m. It is more advantageous if an array of onshore wave energy units as shown in Fig: 1 are linked to offshore wind units with multiple rotors.
### Table 1. Probability densities for a set of data (Fig 2.)

<table>
<thead>
<tr>
<th>Power Range Mega Watts</th>
<th>Pdf (wind)</th>
<th>Pdf(wave)</th>
<th>Pdf(combined)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 -0.5</td>
<td>0.256</td>
<td>1.616</td>
<td>0.016</td>
</tr>
<tr>
<td>0.5 -1.0</td>
<td>0.672</td>
<td>0.384</td>
<td>0.639</td>
</tr>
<tr>
<td>1.0 -1.5</td>
<td>0.624</td>
<td>0.000</td>
<td>0.544</td>
</tr>
<tr>
<td>1.5 -2.0</td>
<td>0.368</td>
<td>0.000</td>
<td>0.528</td>
</tr>
<tr>
<td>2.0 -2.5</td>
<td>0.079</td>
<td>0.000</td>
<td>0.256</td>
</tr>
</tbody>
</table>

The above Table 1 illustrate probability density function estimates for a data set corresponding to Fig 2.

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**PROBABILITY DENSITY FUNCTION**

To estimate probability (Bendat, Julius, S. and Piersol, Allan, G. 1971) of power supply, individual probability densities were estimated for offshore wind power, onshore wave power as well as for combined power from both sources.

\[
P_{\text{eff}} = \frac{N_x}{\Delta x \Sigma N}
\]

\(P_{\text{eff}}\) = probability density function; \(N_x\) = number of samples in a range; \(\Delta x\) = interval width; \(\Sigma N\) = total number of samples

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**Fig. 1. Combined offshore wind energy and onshore wave power units**
ANALYSIS

Three sets of randomly generated data have been considered for the present analysis. Probability density functions of individual power from offshore wind and onshore wave plants and combined power from these two plants were shown in Fig: 2, 3 and Fig: 4. In Fig: 2, individual probability of power supply at or above 1.5 Mega Watts is less than 0.6 whereas it is more and constant up to 2.0 Mega Watts in Combined plants. In case of another independent set of data in Fig: 3, combined probability is higher above 5.0 Mega Watts comparing with individual probabilities. Even though, it is possible in some ranges of power supply, individual probability exceeds combined probability. At higher power ranges combined power supply probability is more than individual probabilities. Thus it ensures possibility of reliable continuous power at higher ranges which is generally the case for peak demand. Fig: 4 also supports and clearly shows that even though, individual probabilities for wave power in ranges 0.0 to 1.0 Mega Watts and for Wind power in the range 2.0 to 2.5 Mega Watts in higher than combined probability, the probability at higher power ranges at more than 2.5 Mega Watts is more than individual probability.

APPLICATION

Even though individual detailed economic and technical feasibility investigations for each location are essential, this type of integrated plants are more environmentally friendly for countries with long coast lines.

LIMITATIONS AND FURTHER INVESTIGATIONS

In this limited study, only few sets of randomly generated data were considered and presented for discussion. It is essential to investigate with real field wave and wind data for each possible case.

CONCLUSIONS

From independent randomly generated data sets, power from both offshore wind energy unit, onshore wave energy plants as well as power from combined plants have been assessed and it was found that probability of continuous supply at higher outputs is more than the individual devise probability of power supply.

REFERENCES


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