LABORATORY 1

DETERMINATION OF THE DISTRIBUTION PARAMETERS OF WIND SPEED DATA

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ABSTRACT

Growing population and the increasing emigration of habitants from rural to urban cities suggest a natural increase in the general energy demand across the globe. This disproportional growth involves a drastic rise in general emission due to the increase of transportation requirements, food generation and general energy necessities. The sum of all these factors boost the negative implications of climate change and in an era of climate awareness, fast implementation of emission hindering techniques is utilized.

Techniques for the reduction of emission are mainly focused on the implementation of renewable generation sources as they are sunlight, wind, waves, tides and geothermal. Nevertheless, most of these techniques share a negative characteristic associated with the incapacity of suppling reliable energy. These effects derive principally due to the difficulty of correctly predicting the sources of the energy.

Wind energy plays a major role in the transition from transition of traditional generation techniques to renewable generation techniques, however important challenges are to be tackle regarding the capacity of correctly forecasting wind intensity and probability of happening.

This work correctly characterizes the wind behavior in the selected site utilizing Weibull distribution method along with three different methods for the factor calculation. The analysis clearly shows no viability for the implementation of wind generation in the selected site due too poor wind energy.

INTRODUCTION

Growing population and the increasing emigration of habitants from rural to urban cities suggest a natural increase in the general energy demand across the globe. This disproportional growth involves a drastic rise in general emission due to the increase of transportation requirements, food generation and general energy necessities. Most of these emissions are greenhouse type that directly feed the effects of climate change, a major antagonist of human development. Along with these catastrophic effects, the outcomes of geopolitics actions fighting for energy sovereignty jeopardizes the development of developing societies across all continents.

The rising concerns on the direct implications of climate change in the mid and long term have boosted the demand for renewable energy generation techniques across the globe. The transition from traditional energy generation to renewable energy generation techniques even though are required; they bring along different challenges in regards with energy reliance. Most of these challenges engender naturally due to an intrinsic characteristic of the so called "renewable sources". Sunlight, wind, waves, tides and geothermal heat are all sources very difficult to predict hence extensive design assessments have to be done in order correctly develop these projects.

High investment for the deployment of renewable technologies have led to reductions in the price of energy generation and finally have reached grid parity when utilizing solar and wind as sources. These reductions are primarily effect of the economy of scales and forecasts indicate that higher reductions will be achieved. Most of these advances in price reduction have been led by the wind energy industry nevertheless its dependency on the wind conditions represent a big risk on the proper reliability of this techniques.

Different vectors have to be define and study to properly state the feasibility of a wind project. The most important variable to be considered, is the wind; in terms of its speed and probability of occurring during a period of time. Wind is highly variable in space and in time[1]. In order to correctly study this phenomenon, different statistic approaches are utilized.

The development of this report will include the analysis of wind samples through a period of time of a selected site. In order to define essential characteristics, as they are: wind speed mean and probability of mean speed of occurring the Weibull Method will be utilized. The factors for the calculation of this method will be obtained by three methods for proper comparison and validation.

1 Hernández-Escobedo, Q.; Manzano-Agugliaro, F.; Gazquez-Parra, J.A.; Zapata-Sierra, A. Is the wind a periodical phenomenon? The case of Mexico. Renew. Sustain. Energy Rev. 2011, 15, 721–728.

Methodology and Associated Theories

The feasibility of execution of a wind park is basically defined by the wind energy resources in the site of study. In order to accurately calculate the available resources, values of the site have to be recorded and probabilistic distributions are to be utilized to define a wind model. Different probabilistic distributions can be utilized, some of these methods are:

1. Rayleigh distribution;
2. Chi-squared distribution;
3. Normal distribution;
4. Binomial distribution;
5. Poisson distribution;
6. Weibull distribution.

For the means of this study, Weibull distribution is to be used due to its relative ease of calculation and proofed accuracy. The Weibull density function is a two-parameter function characterized by two dimensionless parameters: c and k. These two parameters determine the wind speed for optimum performance and the speed range of the site. The distribution is defined below:

$$f(v) = \frac{dF(v)}{dv} = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} * e^{-\left(\frac{v}{c}\right)^{k}}$$

Where v, k and c are wind speed (m/s), shape factor (dimensionless) and scale factor (m/s).

Different methods can be utilized for the correct calculation of the factors k and c, the most common methods are listed below:

1. Maximum likelihood method (MLM);
2. Power density method (PDM);
3. Modified maximum likelihood method (MMLM);
4. Equivalent energy method (EEM).
5. Graphical method (GM);

6. Method of moments (MOM);
7. Standard deviation method (STDM);
8. Matlab Inbuilt Function FitDist

For the means of this study, three main methods are to be utilize:

$\sigma \rightarrow Standard\ Deviation$

$\bar{v} \rightarrow\ Wind\ speed\ mean$

$\gamma \rightarrow Gamma\ function$

- Method of Moments:

$$k = \left(\frac{0.9874}{\frac{\sigma}{\bar{v}}}\right)^{1.0983}$$

$$\bar{v} = c\gamma\left(1 + \frac{1}{k}\right)$$

- Standard Deviation Method:

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086}$$

$$c = \frac{\bar{v}}{\gamma\left(1 + \frac{1}{k}\right)}$$

- Matlab Inbuilt Function FitDist

```
fitdist(wind_speed(:,1),'weibull')
```

k and c are presented as A and B.

Initial data is expected to be inputted to the software tool. Following the data input, the software will calculate initial factors v mean, k and c along with the Weibull distribution for each speed. Finally, the results will be printed in a clear Graphical Interface that will show the total sample number, the mean speed, histogram and the probability vs speed graph.

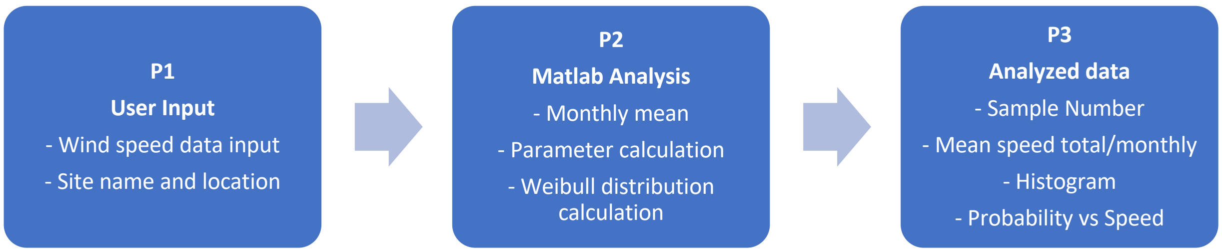

Figure 1: Flow Analysis

Phase 1

Initial wind speed data from a non - disclosed site is obtained. The data is to be cleansed, organized and structured before been upload, as defined below:

Column 1: Year - XXX

Column 2: Month - X

Column 3: Day - X

Column 4: Wind Speed Value - XX.XXX

After the data is depurated the file containing the information is to be save as a .txt fil with the following file name `data_wind_speed_site.txt`.

```
load data_wind_speed_site.txt
```

An extract is presented below as an example:

2005	1	1	7.84000000000000
2005	1	1	9.62000000000000
2005	1	1	6.57000000000000
2005	1	1	6.22000000000000

A window prompts where additional information is requested to be inputted by the user:

```
%*************************************************************************%
%User Data Input
%*************************************************************************%
prompt={'Project Name:','Project Location:'};
dlg_title='Project Initial Information';
num_lines = [1,50];
answer=inputdlg(prompt,dlg_title,num_lines);
P_N = (answer{1});
P_L = (answer{2});
```

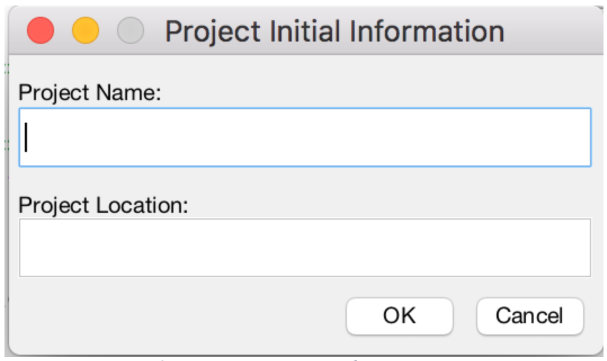

Figure 2: Project Name and Location Prompt

Phase 2

The data inputted is firstly analyzed, where the software tool is able to calculate: sample size, general wind speed, monthly wind speed, wind speed data standard deviation, parameter factors with three different methods and Weibull distribution.

```
%Calculate Sample Size
end_wind_speed = sum(isfinite(wind_speed));

%Calculate Wind Speed Average
wind_speed_avg = mean(wind_speed);


%Calculate Wind Speed Average Monthly
month_average = daily2monthly(data_wind_speed_site);
ma_x = month_average(:,2);
ma_y = month_average(:,3);


%Calculate Wind Speed Standard Deviation
wind_speed_std = std(wind_speed);
%++Standard Deviation Method Factor Calculation++
k_wstdm = (wind_speed_std/wind_speed_avg)^-1.086;
c_wstdm = (wind_speed_avg)/(gamma(1+(1/k_wstdm)));
%++Method of Moments Method Factor Calculation++
k_mom = (0.9874/(wind_speed_std/wind_speed_avg))^1.0983;
```

```
c_mom = (wind_speed_avg)/(gamma(1+(1/k_mom)));
%++Method of Moments Method Factor Calculation++
wif = fitdist(wind_speed(:,1),'weibull');
k_wif = wif.B;
c_wif = wif.A;


%Weibull Probability Calculation Loop
for n=1:end_wind_speed
    %Standard Deviation Method Loop
    wind_speed(n,2) =
(k_wstdm/((c_wstdm^k_wstdm)))*(wind_speed(n,1)^(k_wstdm-1))*exp(-
(wind_speed(n,1)/c_wstdm)^k_wstdm);
    wind_speed(n,3) = wind_speed(n,2) * 100;
    stdm_x(1,n) = wind_speed(n,1);
    stdm_y(1,n) = wind_speed(n,3);
    %Method of Moments Loop
    wind_speed(n,4) = (k_mom/((c_mom^k_mom)))*(wind_speed(n,1)^(k_mom-
1))*exp(-(wind_speed(n,1)/c_mom)^k_mom);
    wind_speed(n,5) = wind_speed(n,4) * 100;
    mom_x(1,n) = wind_speed(n,1);
    mom_y(1,n) = wind_speed(n,5);
    %FitDist In-built Function
    wind_speed(n,6) = (k_wif/((c_wif^k_wif)))*(wind_speed(n,1)^(k_wif-
1))*exp(-(wind_speed(n,1)/c_wif)^k_wif);
    wind_speed(n,7) = wind_speed(n,6) * 100;
    wif_x(1,n) = wind_speed(n,1);
    wif_y(1,n) = wind_speed(n,7);
end
```

Phase 3

The analyzed data is finally presented in a clear Figure screen where final results are graphically analyzed.

RESULTS AND DISCUSSION

In this analysis nondisclosed data is obtained from one monitoring station, the data for one year is captured in hourly intervals. An histogram related to the collected data along with a calculated wind speed values and total sample number are presented in Figure 4 and Figure 5.

	Data
Project Name	'XJTLU Wind Park'
Project Location	'Suzhou, Jiangsu, China'
Total Sample Number	[8760]
Wind Speed Average	[4.8804]

Figure 3: Inputted Data General Information

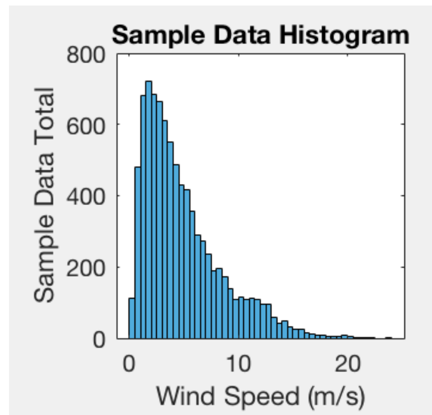

Figure 4: Histogram Collected Data

The processed data is presented in Table 1.

MONTH	AVERAGE WIND SPEED
1	7.8993
2	4.8151
3	4.2251
4	5.1181
5	4.0969
6	3.1684
7	3.3911
8	4.1929
9	4.9353
10	4.6555
11	5.4319
12	6.6006

Table 1: Monthly Wind Speed Average

The generated data is graphically expressed in Figure 3. In the figure obvious higher wind speeds are experienced from December to January and lowest winds speeds are perceived from June to July.

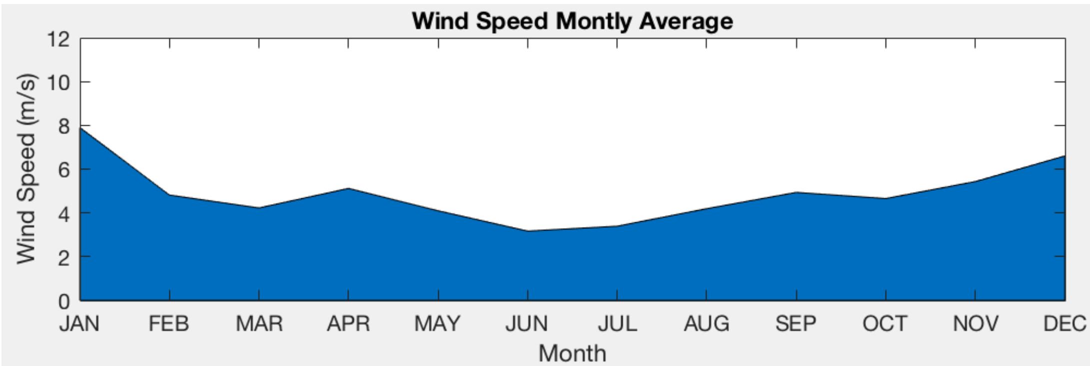

Figure 5: Monthly Wind Speed Average Area Graph

Monthly analysis of Weibull Distribution is obtained and present in Table 2, very high results are obtained; further inferring suggests factors are to be calculated for each month and not global.

		WEIBULL DISTRIBUTION		
MONTH	**AVERAGE WIND SPEED**	**STDM**	**MOM**	**WIF**
1	7.8993	0.0539	0.0534	0.0551
2	4.8151	0.1043	0.1033	0.1065
3	4.2251	0.1145	0.1135	0.1166
4	5.1181	0.0989	0.0979	0.1011
5	4.0969	0.1167	0.1157	0.1186
6	3.1684	0.1302	0.1295	0.1313
7	3.3911	0.1273	0.1266	0.1287
8	4.1929	0.1151	0.1141	0.1171
9	4.9353	0.1022	0.1012	0.1044
10	4.6555	0.1071	0.1061	0.1093
11	5.4319	0.0934	0.0924	0.0955
12	6.6006	0.0733	0.0726	0.0751

Table 2: Monthly Weibull Distribution

Year analysis suggest congruency with prior hypothesis of operation. Final results are exposed in Figure 6.

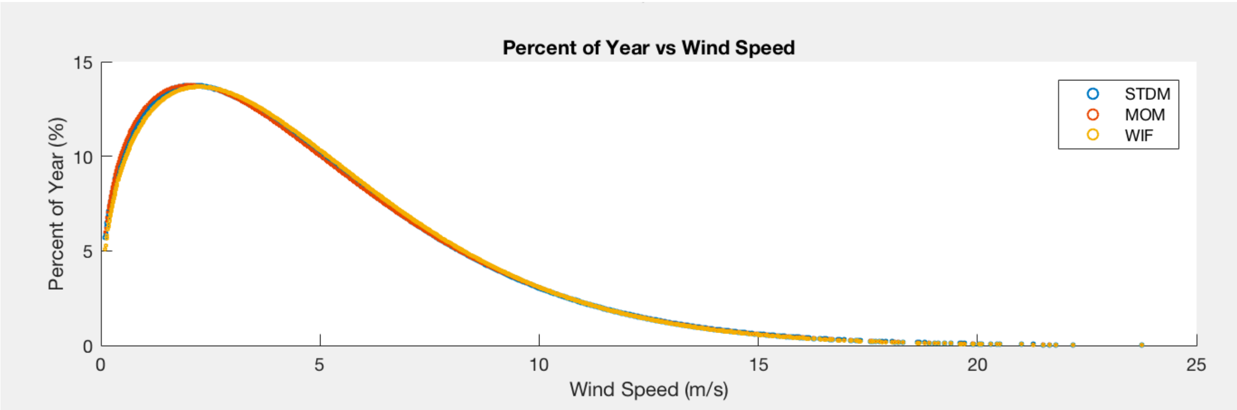

Figure 6: Percent of Year vs Wind Speed

Several methods are utilized to compare and validate results, not major differences are perceived.

YEARLY WEIBULL DISTRIBUTION					
WIND SPEED AVERAGE			4.8804		
STDM		MOM		WIF	
K	C	K	C	K	C
1.3788	5.3415	1.3647	5.3323	1.4107	5.3843

The correct site selection for a wind generation park suggest the Weibull distribution should be close to Raleigh function of k=2. The selected site indicates a significantly lower k through the whole year and with the three methods. The Weibull scale factor (c) corresponds to a 5.3 m/s which indicates the potential of the wind in the studied site; greater values of c corresponds to greater potential of wind.

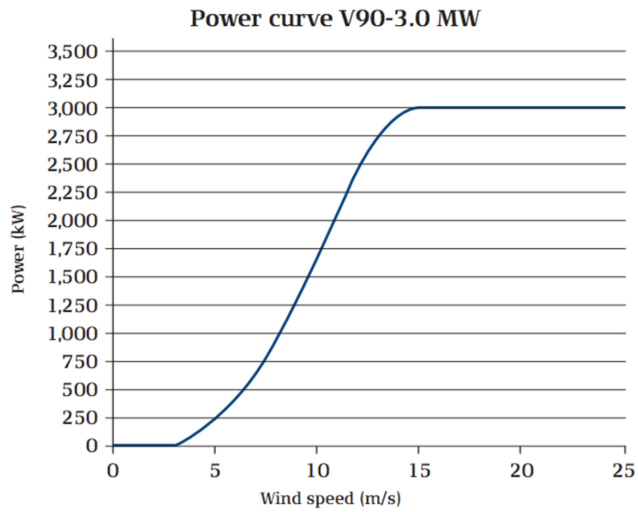

Figure 7: V90 - 3.0 MW Reference

Figure 7 aims to compare required site characteristics for the installation of Vesta V90 3.0 MW wind generation. The Figure in subject shows a minimum cut in speed just above 5 m/s and an optimal wind speed requirement of 15 m/s. The required characteristics of the generator are far above the capabilities of our selected site and will suggest non-viability in the design of a wind generation for the selected site.

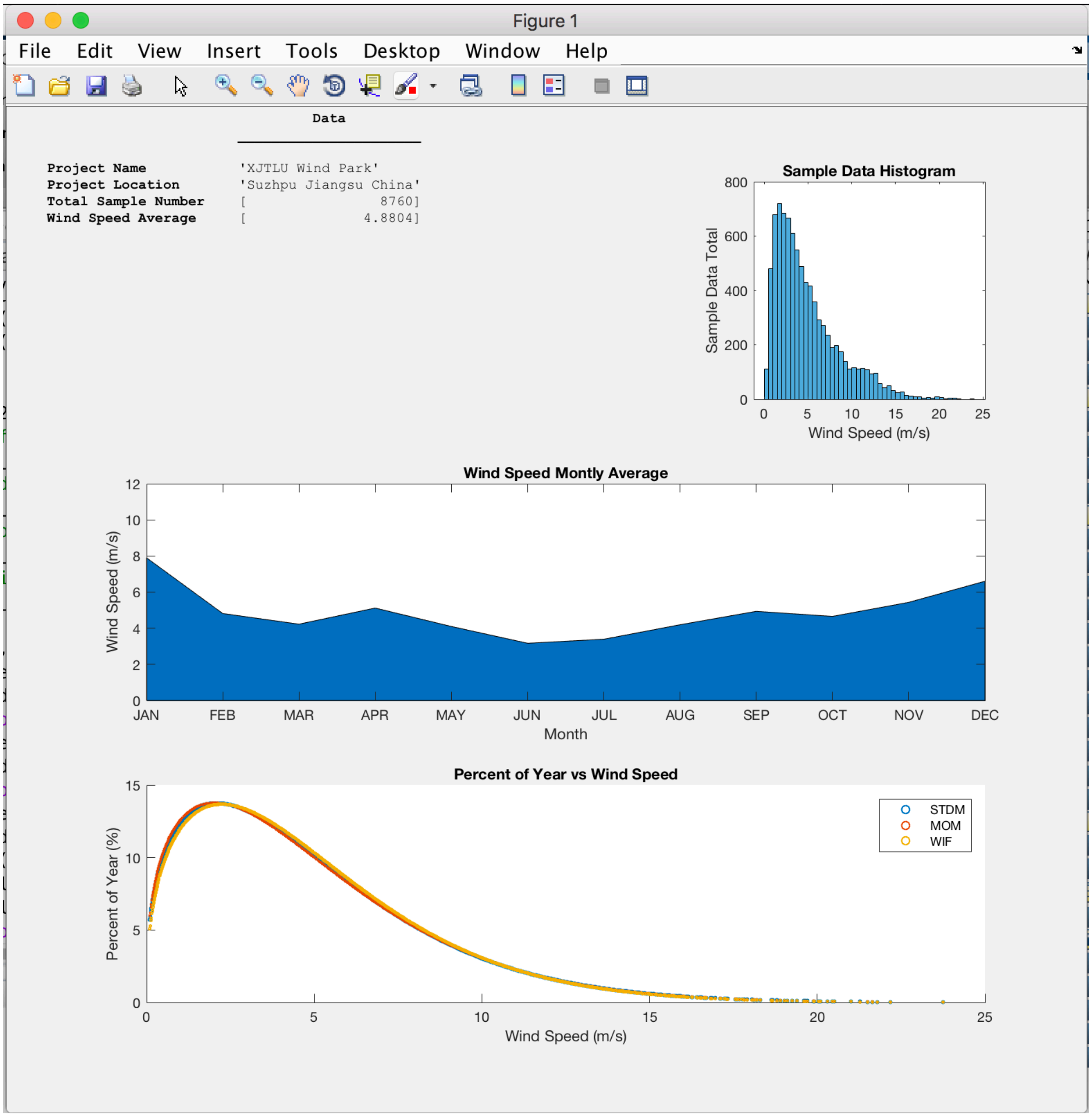

Figure 8: Final Results GUI

Final results are presented in Figure 8, where weak values of factor k and c are clearly visible. The factors naturally shift the graph "Percent vs Wind Speed" to the left that corresponds to low wind speeds during most part of the year.

CONCLUSION

The correct selection of site plays a major role in the feasible operation through time of wind generation applications. For this purpose, a complete and accurate wind assessment is to be done prior to any further design due to the economic implications that may result due to the incorrect analysis. Even though the mathematical tools play a major role in the characterization of the wind assessment, the healthiness of the data is also a major requirement, which means that correct implementation of wind monitors at different altitudes is required for accurate results.

Several different approaches might be applicable for the execution of more accurate results, as they are: the utilization of goodness of fit techniques, measurements at different altitudes and the deeper analysis at monthly level. All of these additional approaches will provide the user a better understanding of the conditions of the site hence more accurate results will be obtained.

The analyzed data in these assignments suggest that an industrial wind generator is not viable for operation in the site. Limitation in the wind potential in the site and low k factor indicate that the site may run short in the implementation of this generation techniques. Site characteristics are compared with those required by an industrial wind generator in order to confirm hypothesis. The developed Matlab tools provides a basic analysis tools for the analysis of considerable big data nevertheless additional variables must be considered.

APENDIXES

a. Master code

```
%*************************************************************************%
%                              PRESENTATION

%Xi'An Jiaotong - Liverpool University
%EEE404-RENEWABLE KINETIC ENERGY TECHNOLOGIES
%Module leader: Dr. Kejun QIAN
%Department of Electrical and Electronic Engineering¬†
%Author: Mateo RAMÍREZ
%Master Program - Sustainable Energy Technologies
%*************************************************************************%
%*************************************************************************%
%Clean and Clear
%*************************************************************************%
clc
clear all
%*************************************************************************%
%User Data Input
%*************************************************************************%
prompt={'Project Name:','Project Location:'};
dlg_title='Project Initial Information';
num_lines = [1,50];
answer=inputdlg(prompt,dlg_title,num_lines);
P_N = (answer{1});
P_L = (answer{2});
%*************************************************************************%
%Load Wind Speed Data
%*************************************************************************%
load data_wind_speed_site.txt
%*************************************************************************%
%Extract Wind Speed Values and Convert Matrix
%*************************************************************************%
wind_speed = data_wind_speed_site(:,4);
%*************************************************************************%
%Analysis of Initial Data
%*************************************************************************%
%Histogram Generation
subplot(3,3,3)
histogram(wind_speed);
title('Sample Data Histogram')
xlabel('Wind Speed (m/s)')
ylabel('Sample Data Total')
%Calculate Sample Size
end_wind_speed = sum(isfinite(wind_speed));
%Calculate Wind Speed Average
month_average = daily2monthly(data_wind_speed_site);
ma_x = month_average(:,2);
ma_y = month_average(:,3);
subplot(3,1,2)
area(ma_x,ma_y)
axis([1 12 0 12])
```

```
xticklabels({'JAN','FEB','MAR','APR','MAY','JUN','JUL','AUG','SEP','OCT','NOV
','DEC'})
title('Wind Speed Monthly Average')
xlabel('Month')
ylabel('Wind Speed (m/s)')
%Calculate Wind Speed Average
wind_speed_avg = mean(wind_speed);
%Calculate Wind Speed Standard Deviation
wind_speed_std = std(wind_speed);
%*************************************************************************%
%Initial Data Print in Figure
%*************************************************************************%
Initial_Data = {'Project Name';'Project Location';'Total Sample Number';'Wind
Speed Average'};
Data = [cellstr('XJTLU Wind Park');P_L;end_wind_speed;wind_speed_avg];
T = table(Data,'RowNames',Initial_Data);
% Get the table in string form.
TString = evalc('disp(T)');
% Use TeX Markup for bold formatting and underscores.
TString = strrep(TString,'<strong>','\bf');
TString = strrep(TString,'</strong>','\rm');
TString = strrep(TString,'_','\_');
% Get a fixed-width font.
FixedWidth = get(0,'FixedWidthFontName');
% Output the table using the annotation command.
annotation(gcf,'Textbox','String',TString,'Interpreter','Tex',...
    'FontName',FixedWidth,'Units','Normalized','Position',[0 0 1 1]);
%*************************************************************************%
%           Weibull Probability Density Function
%*************************************************************************%
%++Standard Deviation Method Factor Calculation++
k_wstdm = (wind_speed_std/wind_speed_avg)^-1.086;
c_wstdm = (wind_speed_avg)/(gamma(1+(1/k_wstdm)));
%++Method of Moments Method Factor Calculation++
k_mom = (0.9874/(wind_speed_std/wind_speed_avg))^1.0983;
c_mom = (wind_speed_avg)/(gamma(1+(1/k_mom)));
%++Method of Moments Method Factor Calculation++
wif = fitdist(wind_speed(:,1),'weibull');
k_wif = wif.B;
c_wif = wif.A;
%*************************************************************************%
%Weibull Probability Calculation Loop
for n=1:end_wind_speed
    %Standard Deviation Method Loop
    wind_speed(n,2) =
(k_wstdm/((c_wstdm^k_wstdm)))*(wind_speed(n,1)^(k_wstdm-1))*exp(-
(wind_speed(n,1)/c_wstdm)^k_wstdm);
    wind_speed(n,3) = wind_speed(n,2) * 100;
    stdm_x(1,n) = wind_speed(n,1);
    stdm_y(1,n) = wind_speed(n,3);
    %Method of Moments Loop
    wind_speed(n,4) = (k_mom/((c_mom^k_mom)))*(wind_speed(n,1)^(k_mom-
1))*exp(-(wind_speed(n,1)/c_mom)^k_mom);
    wind_speed(n,5) = wind_speed(n,4) * 100;
    mom_x(1,n) = wind_speed(n,1);
    mom_y(1,n) = wind_speed(n,5);
    %FitDist In-built Function
```

```
    wind_speed(n,6) = (k_wif/((c_wif^k_wif)))*(wind_speed(n,1)^(k_wif-
1))*exp(-(wind_speed(n,1)/c_wif)^k_wif);
    wind_speed(n,7) = wind_speed(n,6) * 100;
    wif_x(1,n) = wind_speed(n,1);
    wif_y(1,n) = wind_speed(n,7);
end
subplot(3,1,3)
    scatter(stdm_x,stdm_y,5)
    legend('STDM')
    hold on
    scatter(stdm_x,mom_y,2)
    legend('STDM','MOM')
    hold on
    scatter(wif_x,wif_y,3)
    legend('STDM','MOM','WIF')
    title('Wind Speed vs Probability')
    xlabel('Wind Speed (m/s)')
    ylabel('Probability (%)')
    hold off
```

REFERENCES

1. Abul Kalam Azad, Mohammad Golam Rasul and Talal Yusaf, “Statistical Diagnosis of the Best Weibull Methods for Wind Power Assessment for Agricultural Applications”, Energies 2014, 7, 3056-3085
2. Camilo Carrillo, José Cidrás, Eloy Díaz-Dorado and Andrés Felipe Obando-Montaño, “An Approach to Determine the Weibull Parameters for Wind Energy Analysis: The Case of Galicia (Spain)”, Energies 2014, 7, 2676-2700.
3. A. K. Azad[a], M. G. Rasul, M. M. Alam, S. M. Ameer Uddin[b], Sukanta Kumar Mondal, “Analysis of wind energy conversion system using Weibull distribution”, 10th International Conference on Mechanical Engineering, ICME 2013.