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Contingency Assessment for Power System Integrated with Wind Power

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ABSTRACT

Electric demand in the last few years has widely increased, especially in Iraq, where there is a significant difference between the generation and the load in almost all months of the year, particularly in the summer season. One of the important aspects where the operational engineers must take appropriate action in case of an unforeseen catastrophe is power system security. Consequently, the security of the power system depends on the contingency analysis. In order to investigate the impact of wind power on the contingency analysis, three wind farms (WFs) are selected based on the wind's speed availability in Iraq, which are Shaikh Saad, Al-Dujaili, and Al-Fajar. In addition, the wind speeds for these locations are analysed using the Weibull and Rayleigh probability density functions. In this regard, this paper studied and analysed the impact of integrating wind power on the operation of the 132 kV Iraqi grid systems (zone 18). The results show that when line outage contingencies occur (single- and double-line outages), the risk of power flow violations based on the MVA rating will be reduced when integrating wind energy with a 100% integration rate with the Iraqi grid system. Matlab, a programming language, and the Power System Simulator for Engineering (PSS/E) software (Version 32) are used to simulate the proposed approach of integrating wind power into the grid.

1. Introduction

The most important requirement for the proper operation of a power system is the maintenance of system security. A power system's level of operability and safety and the likelihood that it won't engage in severe operations are both determined by the security assessment analysis [1]. Operational engineers must research the severity of the impact of outages and contingencies on the power system as a key component of power system security. Power flow, or load flow, is an important part of this analysis. In addition to having a good plan for future development, they must operate, schedule, and control the power system as it is now. The contingency ranking using the performance index is a method for line outages in a power system that starts with the line with the highest performance index and proceeds its way down based on the calculated percentage of loading lines [2,3].

In the literature, by taking into account the many stochastic realizations of load demand and wind power, the uncertainty in operational decisions has been determined. The data analytics are carried out on the basis of the operations of the energy storage systems and their relevant contingency situations with different grid locations [4]. creates a reliable

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scheduling model for wind-integrated energy systems, taking into account N-1 contingencies for both the gas pipeline and the electricity transmission [5]. As shown in [6], we suggest a two-stage robust security-constrained unit commitment (SCUC) model that takes into account the time autocorrelation of wind/load prediction error and the outage contingency probability of units. Since the wind power variation is modeled using realistic data and a Wiener process, the online contingency analysis can now only provide a deterministic answer as to whether the system is stable or not under specific, believable contingencies [7].

The work in [8] uses the Weibull distribution to examine the characteristics of wind speed data at the Al-Salman location in Iraq. Using the Maximum Likelihood Method (MLM), two crucial Weibull parameters were identified. The probability density function and cumulative distribution function were used to define the ideal wind distribution. A statistical analysis of the wind speed data for Jumla, Nepal, is provided in [9]. In order to do this, the Department of Hydrology and Meteorology's (DHM) daily averaged wind speed data for a ten-year period (2004–2014: 2012 omitted) was evaluated to determine the wind power density, and results showed that the Weibull distribution suited the observed probability distribution better over the course of an entire year in the high-altitude area of Nepal than the Rayleigh distribution. The Weibull and Rayleigh distribution functions, two frequently used functions for fitting a recorded wind speed probability distribution at a specific location in Kosovo during a certain period, are compared in [10], the result shows that the wind distribution in this area produce an accurate average value of wind power.

The research presented here investigates the integration of three proposed wind farms depending on the available wind speed with the Iraqi power grid and demonstrates the results of the impact of this integration on an emergency analysis of the grid using the Matlab programming language and Power System Simulator for Engineering (PSS/E) software Version 32.

2. Power system contingency analysis

In order for a power system to operate securely, it must not only comply with predetermined operating conditions but also continue to function properly in the event of contingencies. In a contingency analysis, reliable contingencies are simulated in order to assess their effects on the performance of the power system. Iraq has recently experienced blackouts rather frequently. Therefore, the primary challenge facing the current Iraqi electrical grid is the creation of a successful system for managing contingencies [11].

One of the most important elements of the reliability of a power system is the estimation of contingency severity. Although dynamic security assessments are also carried out, power system engineers' major focus continues to be on maintaining the power system's static security. It's critical to understand which line or unit outages can cause overloads in power flows or voltages to exceed limitations. Techniques for contingency analysis are used to determine how disruptions may affect systems. Models for contingency analysis Up until all credible failures have been taken into consideration, single failure events (such as one-line or one-unit outages) or multiple equipment failure events (failure of multiple units or lines or their combination) will be examined. For each outage, all lines in the network are checked against their respective limits.

The contingency analysis consists of three basic steps to make it simpler. They are listed below [12]:

1. The process of creating contingencies is the initial stage of analysis. It includes every scenario that might possibly happen in a power system. This procedure entails making contingency lists.
2. Selecting severe contingencies from a list of possibilities that might result in bus voltage and power limit breaches is the second phase of the procedure. The least severe contingency is removed from the contingency list in this phase, while the most severe ones are taken into consideration. Calculating an index for

this procedure reveals the seriousness of contingencies.

3. Evaluation of potential contingencies is the third and most crucial phase since it entails the essential security and control measures that are required to lessen the effects of the most serious potential contingencies on a power system.

2.1 Limits violations of the line's MVA rating

Line outage contingency is one of the most common types of contingencies. When the line's MVA rating is higher than the specified rating, the system experiences this type of contingency. The primary cause of this is the rise in the line's current's amplitude. The lines should be able to tolerate 125% of their MVA maximum because of the way they are designed. According to utility procedures, an alarm condition is raised if the current exceeds 80–90% of the limit.

The overload percentage in power flow for transmission lines based on the MVA rating can be calculated in:

$$\text{overload as a persentge} = \frac{\text{Power Flow in MVA}}{\text{Line Rated in MVA}} \quad (1)$$

3. Wind power overview

The concept of converting wind energy (K.E.) to electric energy is covered in this section. The rotor blades transform K.E. into mechanical energy initially. The kinetic power of wind P_w moving at a speed of V_w across an imaginary region A_T is

$$P_W = \frac{1}{2}\rho\, A_T\, V_W^3 \;,\quad A_T = \pi R_T^2 \quad (2)$$

where AT is the rotor swept area (m^2), R_T is the blade radius (m), V_W is the wind speed (m/s), and ρ is the air density (kg/m^3) [13,14].

The following represents the mechanical power P_T that may be obtained from the wind kinetic power P_w, according to the hypothesis put out by German scientist Albert Betz:

$$P_T = P_w \times C_P = \frac{1}{2}\rho\, A_T\, V_W^3 C_P \quad (3)$$

where C_P stands for the rotor blades' power coefficient. As the C_P value rises, so does the P_T extraction. The highest or theoretical value of C_P, according to Betz, is 16/27, or 0.593. The C_P value for the latest generation of high-power wind farms falls between 0.32 to 0.52.

4. Wind farm requirements

4.1 Wind farm location

Any renewable energy project must choose an appropriate location in order to succeed, both financially and technically. To guarantee that wind farms (WFs) work as intended, it is crucial to choose the right site and turbine model for them. The project's financial returns, simplicity of construction, continuing operations and maintenance, and general safety are all significantly impacted by site selection. This study suggests three wind farms [15]:

- Shaikh Saad in Wasit-Iraq
- Al-Dujaili in Wasit-Iraq
- AL-Fajar wind farm in Thi-Qar -Iraq.

4.2 Analysis of wind speed data

Undoubtedly, the quantity of power a wind turbine will generate annually is greatly influenced by the wind speed. If one wants to be assured of the wind speed, it must be measured on the suggested location before installation. Over the next several years, more advanced prediction software tools may be created, which might lessen the need for monitoring.

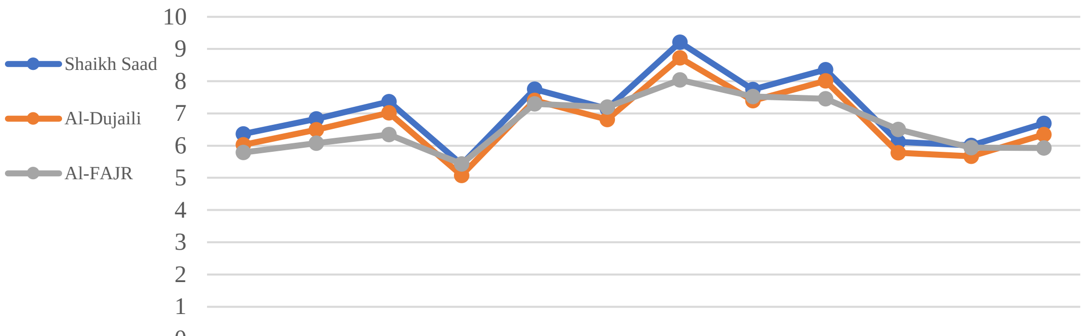
The average, variance, and standard deviation are three important variables that offer significant information about wind speed. The mean value of all wind speeds is what the average wind speed (or wave) is. It is additionally referred to as "expected value." Therefore, the average wind speed at a location is [16,17]:

$$E[v] = V_{avg} = \frac{1}{N}\sum_i^{\infty} n_i\, v_i \quad (4)$$

$$E[v] = V_{avg}\sum_i^{\infty} p_i\, v_i \quad (5)$$

where: E [v] is the predicted wind speed, and n is the number of hours in the data period. if the information was gathered over a year, n = 8760 min.

Figure 1 shows average wind speeds in m/s for WFs at the height of 100 m in 2016.



	1	2	3	4	5	6	7	8	9	10	11	12
Shaikh Saad	6.369	6.833	7.366	5.42	7.749	7.15	9.208	7.74	8.356	6.118	6.01	6.687
Al-Dujaili	6.027	6.491	7.024	5.079	7.407	6.808	8.726	7.399	8.015	5.776	5.669	6.345
Al-FAJR	5.785	6.076	6.345	5.432	7.302	7.196	8.041	7.521	7.456	6.501	5.933	5.932

Figure 1. Monthly average wind speeds in m/s for WFs at the height of 100 m (2016)

Because the measurements might be enormous in quantity, challenging to organize, and difficult to extract specific information from, using raw data for analysis is not simple. Additionally, information for some ranges can be lacking. Instead of using the row data, mathematical functions that capture the characteristics of the data are utilized to overcome these issues. These functions are known as the "probability density functions" (PDF). Weibull and Rayleigh function distributions are two types of mixing probability functions that have already been used to calculate the potential of wind energy [18]. Figures 1 to 7 show the wind speed curve and Weibull and Rayleigh probability density function (PDF) for suggestions of wind farms. The data used in the study was collected over a period of 1 year, from 1/1/2016 to 31/12/2016, at 100 m height [19].

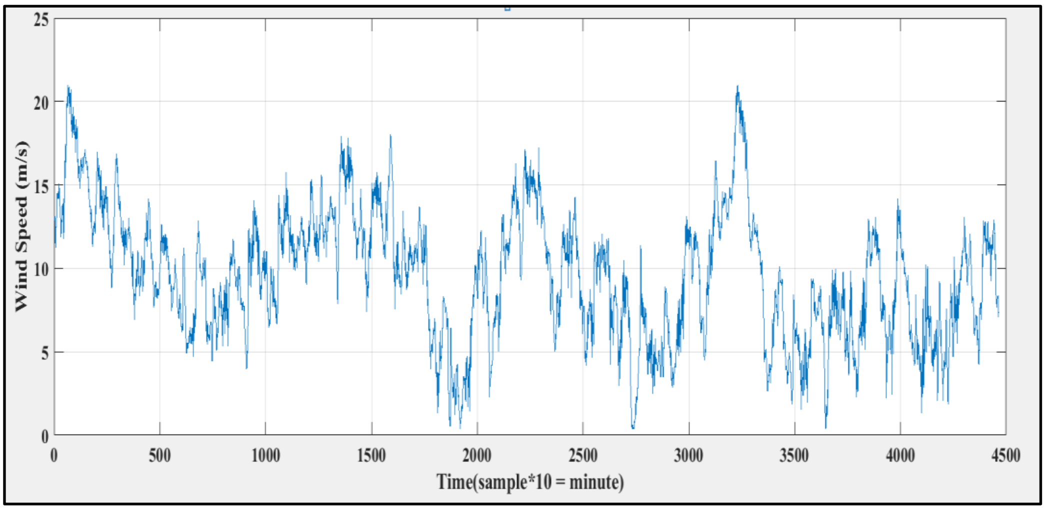
4.3 Wind turbine selection

To meet the estimated yearly energy needs for a certain location, a wind turbine is chosen from the manufacturer's catalog. It was determined that the best wind turbine available in Iraq, with a 3.45 MW capacity, is model number V136 from the Vestas Company [20]. This wind turbine meets the criteria of the current work and is the best option for wind speed.

4.4 Number of turbines in wind farms

Depending on the availability of wind and area, it is suggested that each of these three wind farms have 40 wind turbines, 3.45 MW each, at a height of 100 m, with a total capacity of 138 MW and a total estimated area of 4.8 km^2 [15].

Figure 8 shows the number of days that the wind farms will operate as a percentage of MW generation (0–100%) based on wind speed data and the power-speed curve for VESTAS V136 in [8]. From this figure, it is clear that the number of days during which the wind farms will operate at 100% is more common in the summer season, especially in July, while the number of days when the wind farms will not operate is lowest in the spring season, especially in April.



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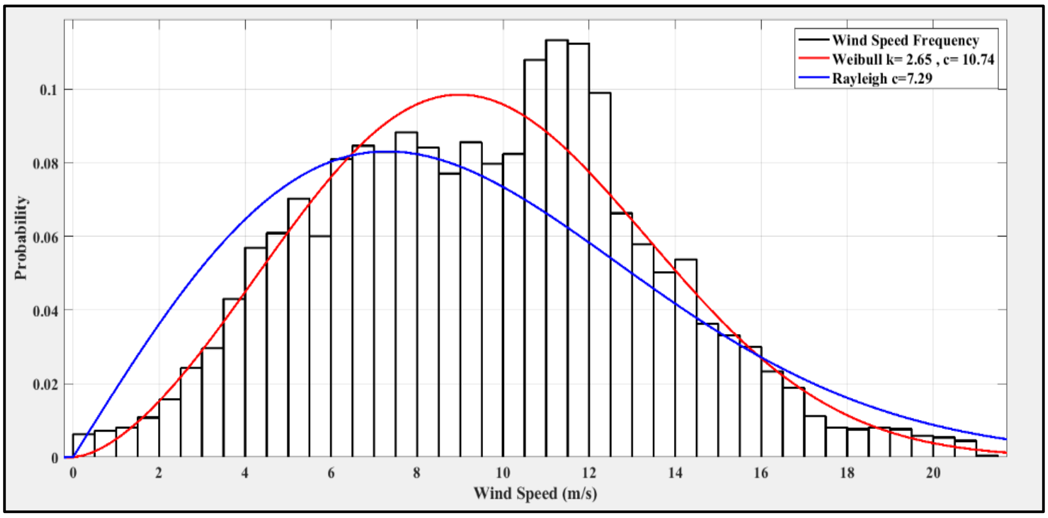

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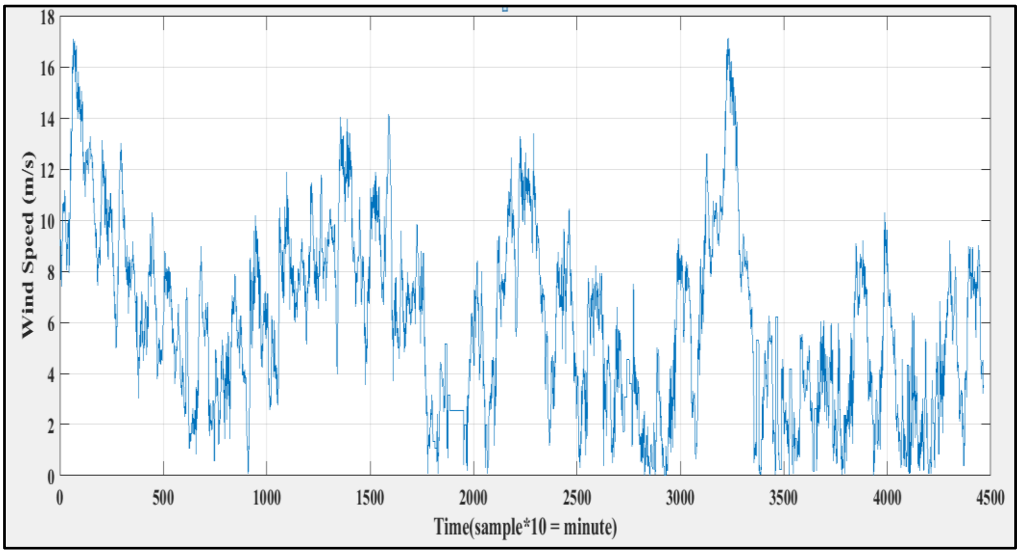
Figure 2. Data for July at Shaikh Saad (4464 minutes) (a) Wind speed curve (b) Weibull & Rayleigh probability density function (PDF)



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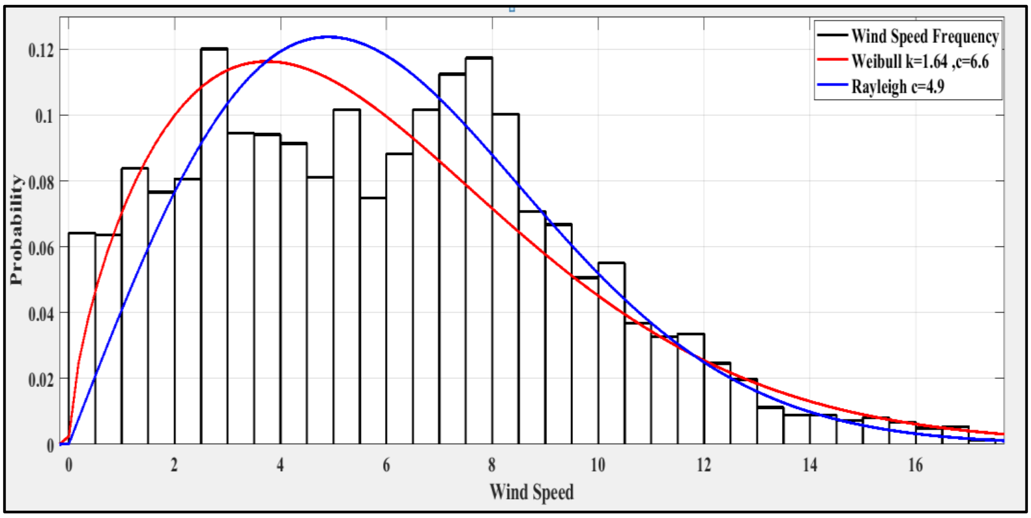

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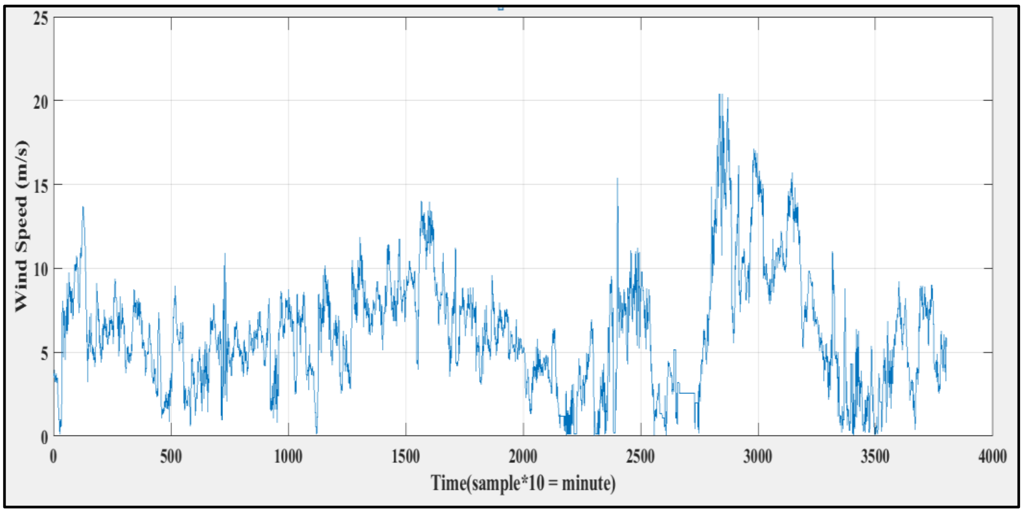
Figure 3. Data for April / 2016 in Shaikh Saad (4464 minutes) (a) Wind speed curve (b) Weibull & Rayleigh probability density function (PDF)



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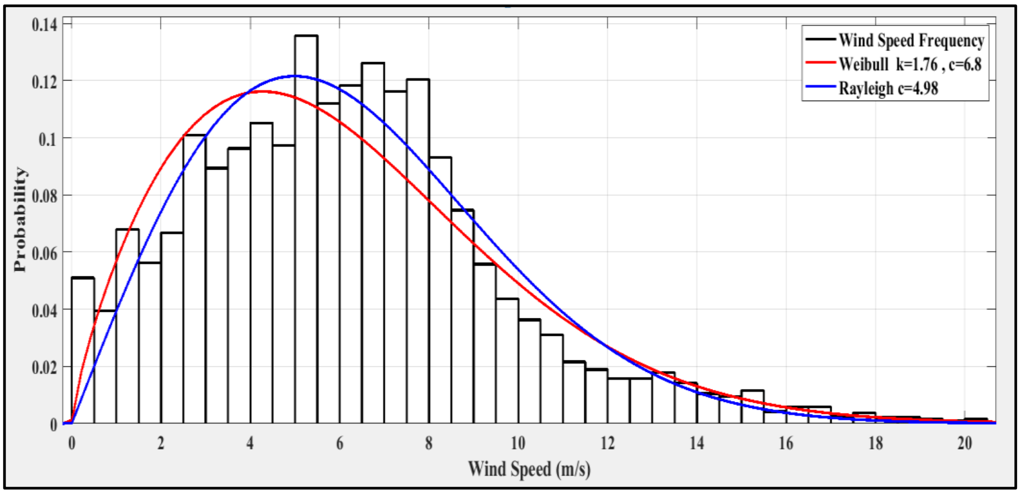

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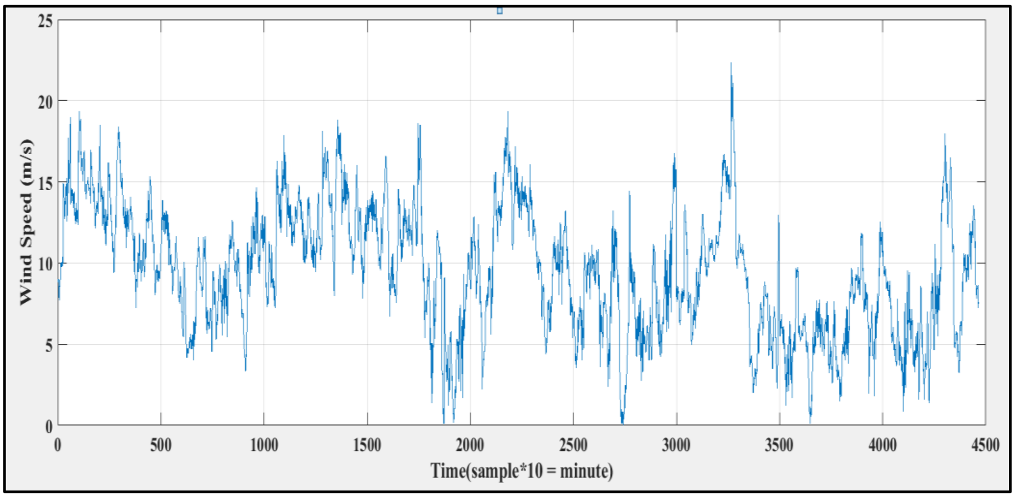
Figure 4. Data for April / 2016 in Al- Dujaili (4464 minutes) (a) Wind speed curve (b) Weibull & Rayleigh probability density function (PDF)



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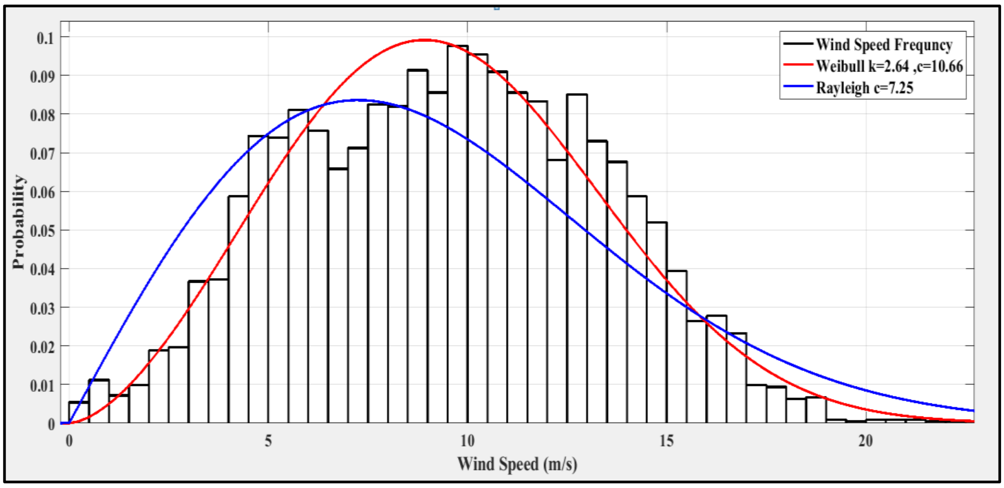

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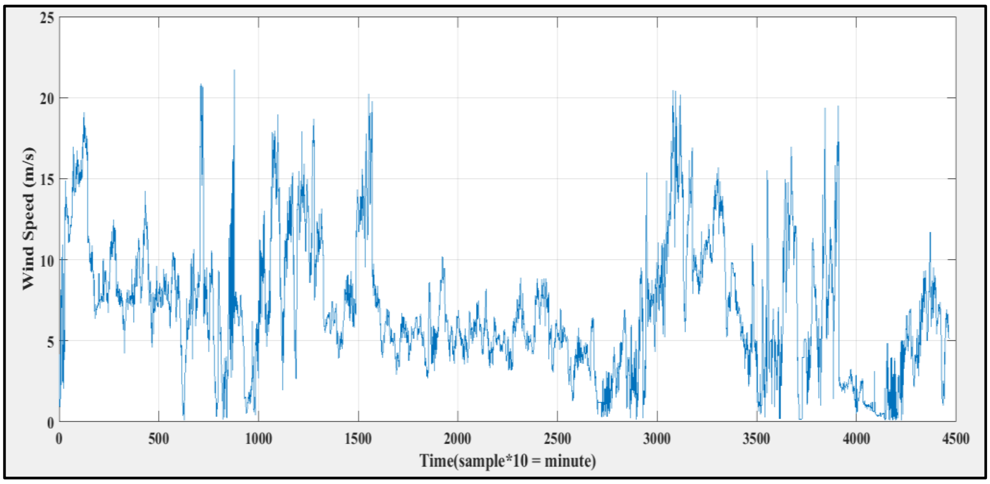
Figure 5. Data for July / 2016 in Al- Dujaili (4464 minutes) (a) Wind speed curve (b) Weibull & Rayleigh probability density function (PDF)



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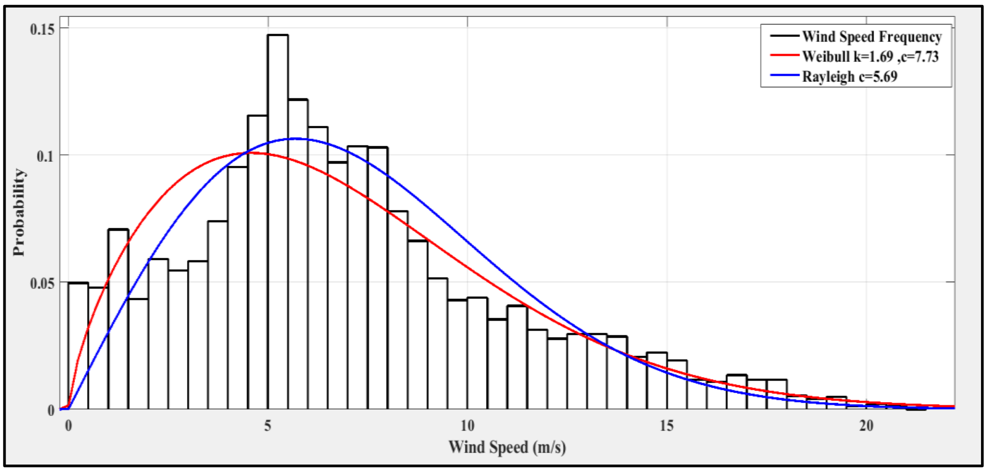

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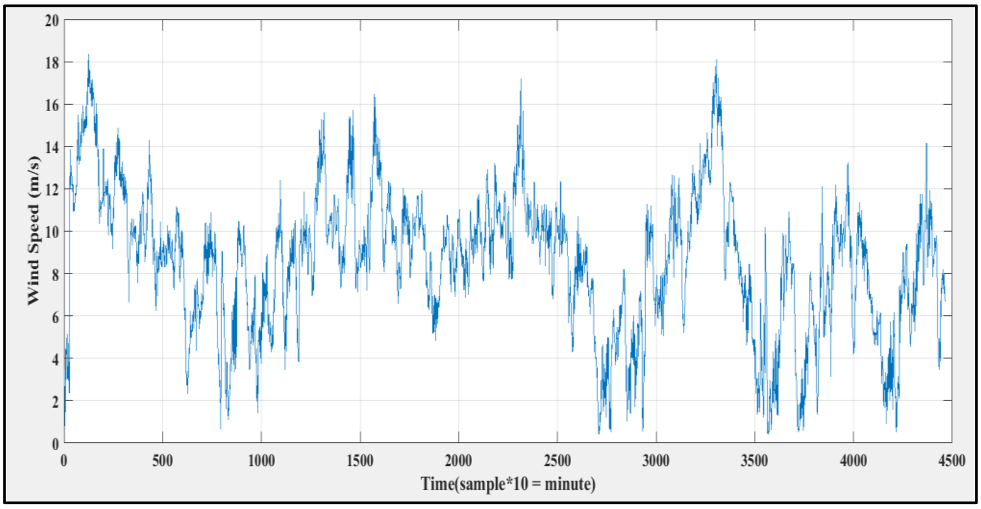
Figure 6. Data for April / 2016 in AL-Fajar (4464 minutes) (a) Wind speed curve (b) Weibull & Rayleigh probability density function (PDF)



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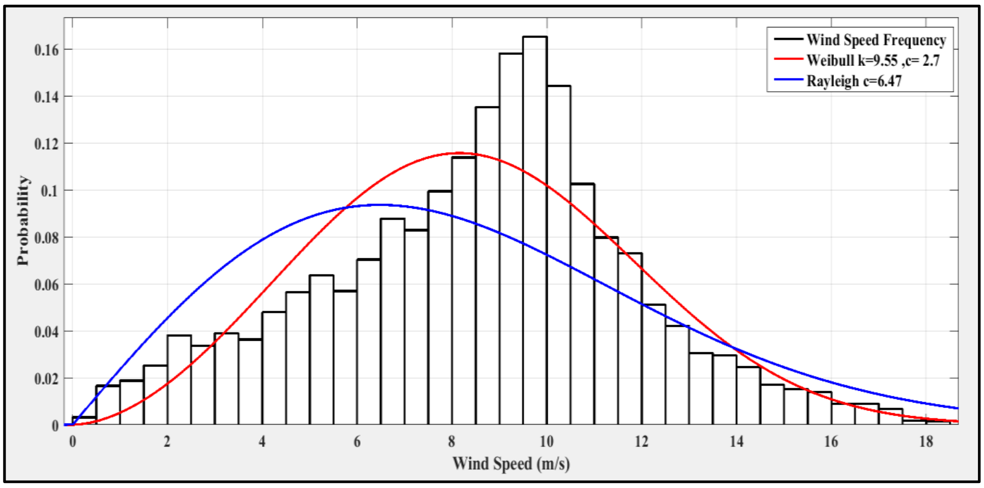
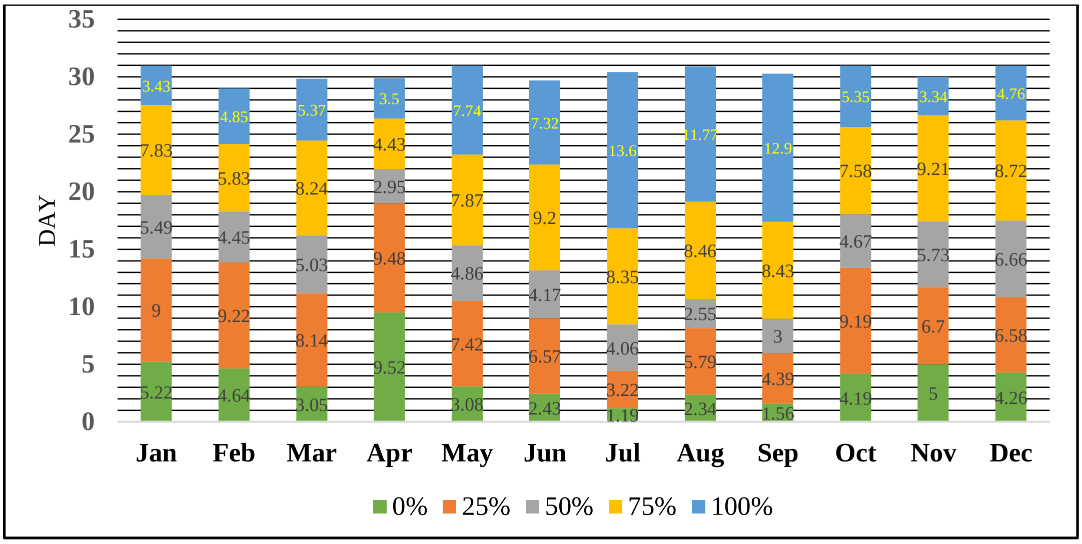


b)

Figure 7. Data for July/2016 at AL- Fajer (4465 minutes) (a) Wind speed curve (b) Weibull & Rayleigh probability density function (PDF)



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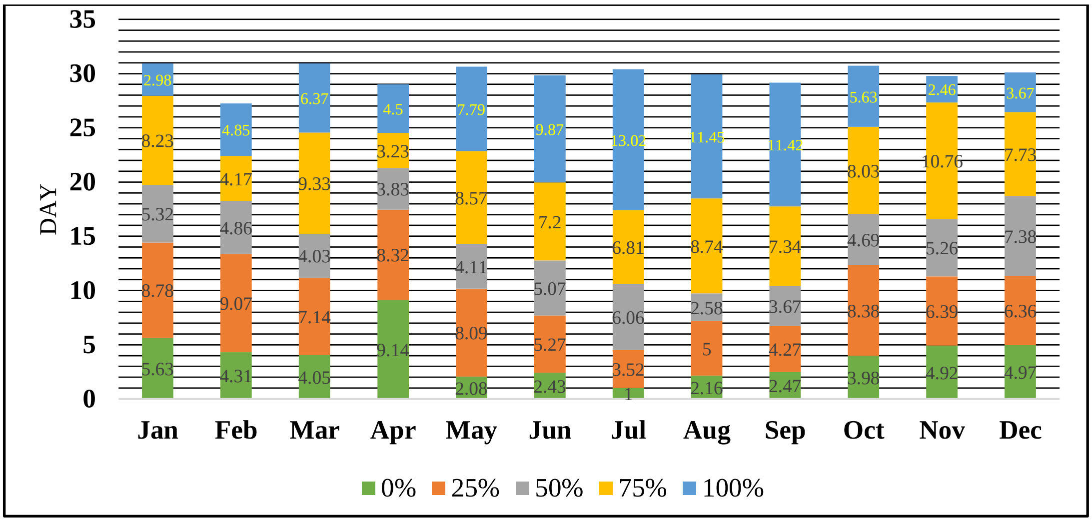

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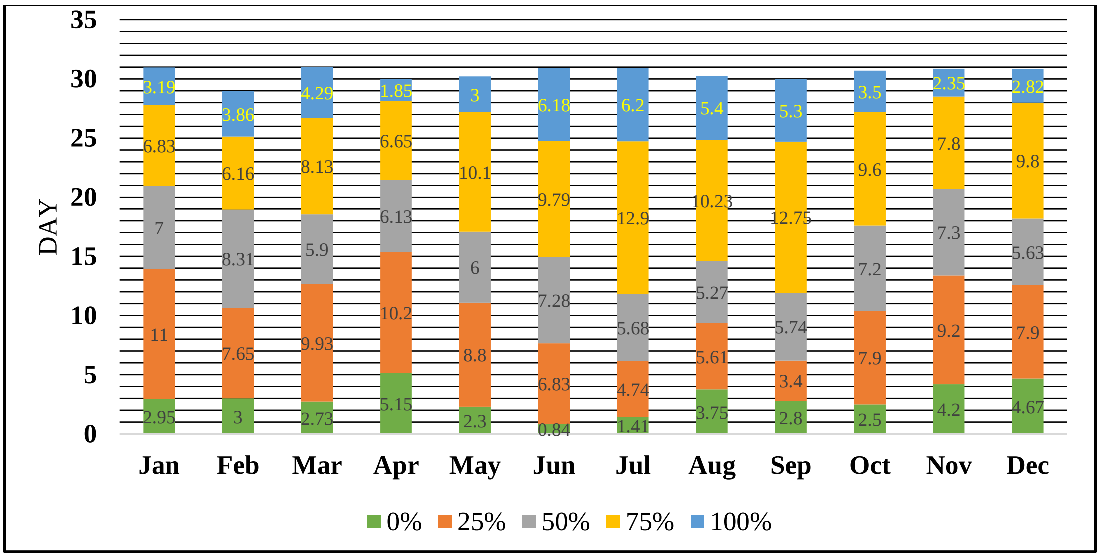

c)

Figure 8. Number of days Vs. generator availability, a) Shaikh Saad WF b) Al-Dujaili WF c) Al-Fajar WF

5. Results and discussion

The 132 kV Iraqi gird system comprises of (362) bus bars, (38) generator buses, (323) load buses, (73) autotransformers and (567) transmission lines. The 38 generating stations are of different capabilities of MW generation and MVAr generation/absorption. The data represent the state of operation for summer season on July, 1, 2022 [21]. For Iraqi power system, three WFs have been suggested and as follows:

a. Shaikh Saad WF (40 turbines, total capacity = 138MW) can be connected to Shaikh Saad bursar though transmission line of 15 km length.
b. Al-Dujaili WF (40 turbines, total capacity = 138MW) can be connected to Al-Dujaili busbar though transmission line of 9 km length.
c. AL-Fajar WF (40 turbines, total capacity = 138MW) can connected to Al-Rifai busbar though transmission line of 20 km length.

The power flow violation approach adopted in this paper is based on MVA rating monitoring after line outage contingencies occurred. This approach involves running simulations for each scenario and keeping an eye on the percentage of loading lines (%) on each line. If the power flow exceeds the line's maximum limit or capacity, it is recorded as a violation.

5.1. Single-Line outage contingency

Contingency analysis is applied to 132 kV Iraqi grid zone 18 (Wasit Governorate). The total lines in this zone are 22 lines. Therefore, there are 22 possibilities for single-line outage contingencies. Table 1 shows the simulation results without and with WFs (the impact of multiple WFs as a percentage of integration is 100%) for ranking overload in transmission line indices for the top eight single-line outage contingencies. When KUTP-DBNI line outage occur from the grid due to some emergency cases, three lines (rank 1) go out by protective devices since they are running beyond their MVA limit. The power flow violation based on the MVA rating will be reduced when integrating WFs.

Table 1: Single line outage analysis using PSS/E and Matlab programs

No. of Case	Line outage	Critical Line	Percentage of loading lines (%) without WFs		Percentage of loading lines (%) with WFs		Rank
			PSS/E	Matlab	PSS/E	Matlab	
Case 1	KUTP-DBNI	KUTP-4KUT	150.9	139.4	113.7	**Safety side***	1
		4KUT-KUTO	151.5	138.8	**Safety side**	**Safety side**	
		KUTS-DJLA	102.4	**Safety side**	**Safety side**	**Safety side**	
Case 2	4KUT – KUTO (1)	4KUT – KUTO (2)	132	114.3	105.8	Safety side	2
		KUTS - DJLA	102.1	**Safety side**	**Safety side**	**Safety side**	
		DJLA-RFAI	108.8	**Safety side**	**Safety side**	**Safety side**	
Case 3	4KUT-NMYA (1)	4KUT – NMYA (2)	143.7	131.4	110.6	**Safety side**	3
		4KUT-KUTO	151.0	144.5	**Safety side**	**Safety side**	

*Percentage of overload below 100%

Case 4	KUTO-KUTS	4KUT – KUTO	139.6	121.3	115	**Safety side**	4
		KUTS - DJLA	102.2	**Safety side**	**Safety side**	**Safety side**	
Case 5	KUTS-KUTN	KUTS-KUTO	111.7	**Safety side**	**Safety side**	**Safety side**	5
Case 6	4KUT-KUTN	4KUT-KUTO	175.8	153.6	**Safety side**	**Safety side**	6
Case 7	KUTS-DJLA	DJLA-RFAI	108.8	**Safety side**	**Safety side**	**Safety side**	7
Case 8	KUTS-KUTN	4KUT-KUTO	173.3	161	**Safety side**	**Safety side**	8

4.2 Double line outages contingency

There is a large number of possibilities for double line outages contingency and many of these contingencies make the load flow solution to be diverged. In this section, the double line outages contingency is applied to zone 18 with and without WFs (impact of multiple WFs as percentage of integration is 100%). Table (2) lists the top four overloads in power flow due to double line outages contingency using PSS/E and Matlab programs.

Table 2: Double line outage analysis using PSS/E and Matlab programs

No. of Case	**Line outage**	**Critical Line**	**Percentage of loading lines (%) (MVA) without WFs**		**Percentage of loading lines (%) (MVA) with WFs**		**Rank**
			PSS/E	**Matlab**	**PSS/E**	**Matlab**	
Case 1	KUTP-DBNI & KUTP-4KUT (1,2)	4KUT-NMYA	134.8	125.6	**Safety side**	**Safety side**	1
		4KUT-KUTO	205.3	191.9	177	159.4	
		NJSAN-DBNI	184	175.4	109	**Safety side**	
Case 2	4KUT-NMYA & KUTS-KUTN	4KUT-KUTO	241.5	228.5	133.7	129	2
		4KUT-KUTS-	196.8	183	**Safety side**	**Safety side**	
Case 3	SUWR-AZIZ & KUTS-KUTN	4KUT-KUTO	199.2	186.7	116.8	107.4	3
		KUTP-AZIZ	118.4	**Safety side**	**Safety side**	**Safety side**	
		4KUT-NMYA	138.1	125.4	**Safety side**	**Safety side**	
Case 4	4KUT-KUTO & SUWR-AZIZ	4KUT-KUTS	207.5	163.7	127.3	115.7	4
		4KUT-NMYA	114.2	**Safety side**	**Safety side**	**Safety side**	
		NJSAN-DBNI	106	**Safety side**	**Safety side**	**Safety side**	

5. Conclusions

This paper presents the impact of integrating wind farms into Iraqi power grid operations by selecting the most suitable Iraqi location during several grid contingency scenarios. Three wind farms have been suggested, depending on the available wind speeds, in the following areas: Shaikh Saad and Al-Dujaili wind farms are located in the city of Wasit-Iraq, AL-Fajar Wind farm is located in the city of Thi-Qar-Iraq. Each of these three wind farms suggested having 40 wind turbines (Total capacity of 138 MW) at 100 m height, with a total estimated area of 4.8 km^2. The proposed approach of wind power integration into the grid has been simulated using the Matlab programming language and Power System Simulator for Engineering (PSS/E) software Version 32. The following conclusions are made:

- According to the wind speed analysis for wind farms by the Weibull function and Rayleigh distribution, Sheikh Saad wind farm is one of the most promising areas for installing wind turbines.
- The occurrence of various types of contingencies (single- and double-line outages) will be improved when integrating wind energy with the Iraqi grid system.
- The results obtained in the analysis of the system of the Iraqi grid show that the performance is very close between PSS/E and Matlab, but there is a difference in values because of which the MVar values were changed and a large number of buses have been dispensed in Matlab.

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Appendix:

Abbreviation of busbar in the Iraqi power grid

Abbreviation	Actual Name
AZIZ	Azizia-132kV
KUPT	Kut Steam Power Station (Wasit Thermal) 400kV
DBNI	Al-Dabouni-132kV
DJLA	Busbar Al-Dujaili-132kV
4KUT	Kut Substation 400kV
KUTO	Old Kut-132kV
KUTS	South Kut-132kV
KUTN	North of Kut-132kV
NMYA	Numaniyah-132kV
RFAI	Al-Rifai-132kV
SUWR	Al-Sowera-132kV