# A Methodology to The Safe Operation of Mobile Crane in Erection of Wind Turbine

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**Abstract:** In the construction of wind farms, mobile crane is the main equipment used to lift and erection of wind turbine. Always, wind farms are constructed on sites of high wind speed which has a negative influence on crane stability and safe lifting of wind turbine parts. Therefore, this paper presents a methodology to optimize crane safety during erection of wind turbine considering wind speeds and total project time, the suggested methodology based on genetic algorithm technique.
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## 1. Introduction

### 1.1 Basics of Wind

The Earth continuously releases into the atmosphere the heat received from the sun, but unevenly. Wherever, more heat is released the air warms up and its density reduces and rise, while in the cool air zones the pressure of air increases, thus drawing cooler air flowing over the earth's surface. The air moves from the areas of higher pressure towards those of lower pressure, the movement of air masses between different zones is known as wind [1].

### 1.2 Wind Speed Forecasting

To forecast the wind speed, variant methods have been used, most of these methods based on support vector machines, artificial neural networks (ANN), and genetic algorithms (GA). Support vector machines (SVM) applied to predict wind speed by [2]. The SVM had the minimal value of the mean square error in comparison to back propagation neural networks. A hybrid wind speed prediction model includes wavelet transform has been proposed [3]. A short-term wind speed forecasting model based on artificial neural network and wavelet packet decomposition was proposed [4]. The proposed system achieved minimal mean absolute percentage error when it was compared with other hybrid methods. Empirical mode decomposition algorithm combined with neural network and applied for wind speed forecasting [5]. The results show that the suggested model has the minimum statistical error regarding the mean absolute error.

### 1.3 Wind Effects on Crane Operation

The crane is considered as the main equipment in the construction of wind farms where plays an important role in lifting and handling a variety of materials. Wind forces act upon both a mobile crane and the lifted load, may well be affect both the durability and stability of the crane, and safe handling of the load. One of the destructive crane accidents ever to have occurred, the Big Blue collapse on the Miller Park Stadium project, was primarily caused by wind and poor ground conditions [6]. However, consideration of the effect of wind on during lift analyses of crane operations is not widely practiced.

The stability of a truck crane affected by geometrical and load conditions [7]. A mathematical model for identifying the dynamic forces act upon the slewing crane structure during load transport has been accomplished [8]. Also, a mathematical model including numerical simulation of mobile crane operation has been developed in order to ensure minimization of crane swings [9].

In practice mobile cranes may become unstable as a result of penetration of the outriggers into the soil, and about 20% of overturning incidents occurred when the hook load was less than the net rated load [10]. Thus, this research presents a methodology to enhance the safe operation of mobile crane during lifting parts of a wind turbine in conditions of high wind speeds.

### 1.4 Wind Turbine

Wind turbine used to convert the wind kinetic energy into electrical power. Once the construction of the foundation is completed the wind turbines are lifted and installed above the foundation using cranes. The wind turbine consists of four parts; the turbine tower that holds; nacelle, Hub, and blades. Components of wind turbine described by their dimension or weight or both, in Table 1, the hub height ranges between 61.5 m and 80 m for wind turbine capacity of 1.5MW, and 2MW respectively [11].

**Table 1: Wind Turbine Parts; Weight and dimensions**

| Parts of wind turbine | Dimension/Height | Weight |
|---|---|---|
| Tower | Up to 100 m | Up to 150 ton |
| Nacelle | …. | Up to 100 ton |
| Hub | …. | Up to 15 ton |
| Blade | up to 40 m | up to 6.5 ton |

**2. Problem Statement**

Always, wind farms are constructed in high wind speed regions. Besides weight, shape and size of load, wind speed and direction, have a main effect on crane stability and lifting process. Effect of strong wind is evident in safety problem where, high wind speed could lead to crane overturning, especially during times of fluctuating wind speed and the occurrence of wind gusts. Morever overturning of cranes leading to cancel lifting process, consequently delays in the time schedule of the project.

**3. Research Objective**

The main research objective is to presents a methodology to enhance and optimize mobile crane safety in erection of wind turbine. This methodology based on genetic algorithm technique and will be used as an operational planning tool before an individual lift to assess the safety consequences of conducting a lift on any particular day.

**4. Probosed Methodology**

In order to achieve the aforementioned objectives, the following subsections are the basic elements of the proposed methodology. The flowchart of the proposed algorithm is shown in Fig.2.

**4.1 Forecasting of Wind Speed**

The prediction of wind speed is done based on the next formula [12]. This forecasts wind speed at any time (t) using data of wind speed at a previous time (t−1).

$$Y_t = a_0 + a_1 Y_{(t-1)} + a_2\, Y_{(t-1)} t^2 + \ldots + a_n\, Y_{(t-1)} t^n \qquad (1)$$

Where $Y_{t-1}$ is the wind speed of the previous hour and the coefficients $a_0$, $a_1$, $a_2$,….., $a_n$ can be obtained by using the Least Square method.

**4.2 Computation the Forces Affecting Both Crane and Lifted Load**

**4.2.1 Computation the overturning forces**

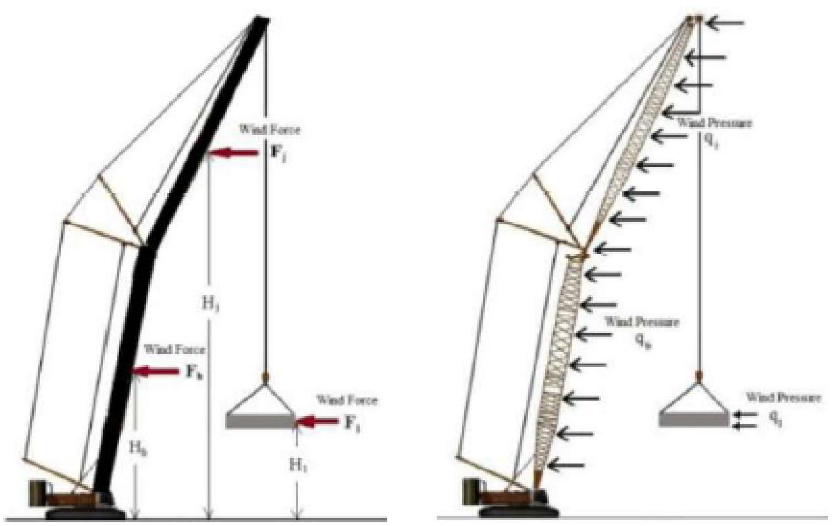


**Figure 1. Wind Acting on Mobile Crane**

**Table 2: Drag factor, according to European Standard for mobile cranes (EN13000, 2010)**

If the wind hits the load, then it swings in the direction of the wind, consequently the load no longer acts vertically downwards on the boom. Also, the swing of load causes the crane boom to swing, this swinging of the boom causes the cranes loading to increase. Wind forces affecting the crane and the lifted load as shown in Fig.1 are calculated using the general equation:

$$F = 0.5\, \rho . V_z^2 .\, C_w .\, A_p \qquad (2)$$

Where: ρ = Air density =1.25 kg /m$^3$

Vz = Wind speed (m / s) at a height (Z) above ground

$$Vz = \{ (Z/10)^{0.14} + 0.4\} * V_f \qquad (3)$$

Where $V_f$ is the mean forecasted wind speed determined at 10 m above ground level as mentioned in article 4.1.

$C_w$ = Drag coefficient or wind resistance factor, depending on shape of load, example of shapes and corresponding drag factors mentioned in Table 2.

$A_p$ = Projected surface of a lifted load

$F_b$ = Wind force on boom, Hb = Height from ground to central of boom

$F_j$ = Wind force on job, Hj = Height from ground to central of jib

$F_l$ = Wind force on lifted load, Hj = Height from ground to central of lifted load

The overturning moment:

$$M_{wi} = \sum F_x . H_x = F_b . H_b + F_j . H_j + F_l . H_l \qquad (4)$$

| Shape of body | Drag factor Cw |
|---|---|
| Plate / cube | 1.1 to 2.0 |
| Cylinders | 0.6 to 1.0 |
| Ball | 0.3 to 0.4 |
| Hemisphere (front) | 0.2 to 0.3 |
| Hemisphere (rear) | 0.8 to 1.2 |
| Wind power plant rotor | Approximately 1.6 |

### 4.2.2 Computation the stabilizing forces

The overturning moment Mw is counteracted by the stabilizing moment Mu with an opposite direction, the crane is stable if the stabilizing moment Mu is greater than the overturning moment Mw by the value of ΔM ≥ 0, Where:

The stabilizing moment:

$$Mui = \sum\nolimits_{i=1}^{n} ( Gj * dij - R_{yb} * x_b ) \qquad (5)$$

*Gj* = is the weight of the crane element, (e.g. Weight of the outrigger system, crane base weight, weights of hydraulic cylinders, and hook weight etc...), and $R_{yb}$ is the vertical reaction of the outrigger system.

*di*j = distance of the centroid of the element *j* from the tip-over axis *i* in the projection on the horizontal plane.

$x_b$ = distance from the centroid of outrigger to the crane's center of gravity.

### 4.3 Computation The allowable Wind Speed for Crane Operation

The maximum allowable wind speed for lifting any load with mass of (mi) and projected surface area (Ap) can be calculated with a formula of European Standard for mobile cranes (EN13000, 2010):

$$V_p = Min.\ of \{ Vmax\text{-}chart\ or\ Vmax\text{-}chart * ( 1.2\, m_i / C_w . A_p )^{\wedge 0.5} \} \qquad (6)$$

Where:

mi =The load mass (including; lifting load, hoist load, and hook block)

$A_W$ = The surface area exposed to wind = $C_w . A_p$

$V_{max\text{-}chart}$ =The maximum wind speed per the load chart of the selected mobile crane.

### 4.4 Formulation of Mathematical Model

The above problem is formulated as assignment linear programming as follows:

The objective is to maximize the total crane safety (CS):

$$Max.\ f = \sum\nolimits_i^n CS \qquad (7)$$

Subject to:

Carrying capacity (crane capacity) constraint:

$$mc > mi \qquad (8)$$

Constraint of allowable wind speed for crane operation:

$$V_p > V_f \qquad (9)$$

Stabilizing Constraint: $Mu > Mw$ (10)

Rigging height constraint:

$Hr/tan\Theta \geq b$ (b = load breadth/2) (11)

(i.e. rigging height has to be tall enough to avoid boom collision with the load)

Crane configuration constraints:

$$Rmin \leq R \leq Rmax \qquad (12)$$

$$Lmin \leq L \leq Lmax \qquad (13)$$

$$\Theta min \leq \Theta \leq \Theta max \qquad (14)$$

Where:

R = is the operating radius which is defined as the distance between the centroid of the lift and the center of rotation of the crane.

L = is the boom length, which is defined as the distance from the crane's pivot to the centroid of the load.

ϴ = is the lift angle which is defined to be the boom to ground operating angle.

R, L, and ϴ have a minimum and maximum range as defined in the specifications of the selected mobile crane.

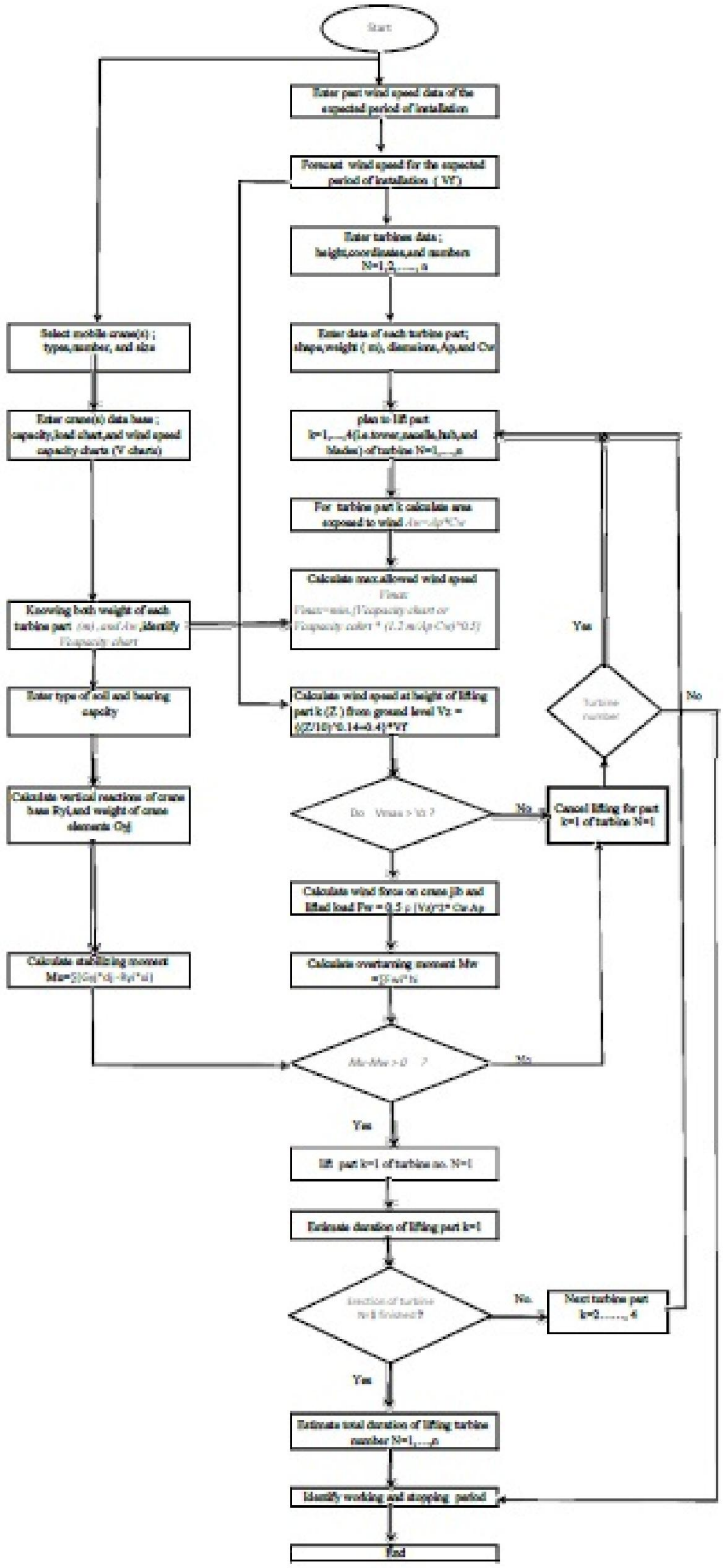


Figure 1.Flow chart of the proposed methodology

**5. Conclusion**

The suggested methodology presents the critical elements affecting stability and safety of mobile cranes in erection wind turbine. Also, presents an operational planning tool helps to execute the lifting of wind turbine parts without any accident or damage to the crane used, considering wind speed and time of the project.

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