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HYDRODYNAMIC ANALYSIS OF SEMISUBMERSIBLE TYPE FLOATER FOR WIND TURBINE

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ABSTRACT

Offshore wind turbine is one of the promising energy resources which can practically curtail the fossil fuel energy consumption and present a form of clean energy. As a matter of fact we know that around 10 million MW energy is available in earth's wind .The concept of offshore wind turbine is based on either fixed structure as jacket or a floating offshore platform like semisubmersible or tension leg platform. In the present context a detailed hydrodynamic analysis of floating offshore wind turbine supported by floating semisubmersible type structure is carried out. floating structure is selected for the analysis as it is assumed that for certain water depths floating wind turbine (for which semisubmersible is one of the choices as a support structure) will have better economic feasibility than bottom mounted wind turbine also floating foundations offer greater flexibility in terms of sit selection of wind forms and if properly designed may result in comparable availability with offshore wind turbines on fixed foundations. The present analysis is mainly focused on 5 MW NREL wind turbine.

Keywords Offshore Wind Turbine, semisubmersible type structure Hydrodynamic Analysis, Mooring Line Analysis

1. INTRODUCTION

Offshore wind turbine is one of the promising energy resources which can practically curtail the fossil fuel energy consumption and present a form of clean energy. As a matter of fact we know that around 10 million MW energy is available in earth's wind .In the present context a detailed hydrodynamic analysis of floating offshore wind turbine supported by floating semisubmersible type structure is carried out. floating structure is selected for the analysis as it is assumed that for certain water depths floating wind turbine (for which semisubmersible is one of the choice as a support structure) will have better economic feasibility than bottom mounted wind turbine also floating foundations offer greater flexibility in terms of site selection of wind forms and if properly designed may result in comparable availability with offshore wind turbines on fixed foundations. According to Dongsheng (2012) Catenary mooring system provide restoring force to the platform depending on the weight of the mooring line but at larger water depths weight of chain is one of the constraints. Semi taut mooring supplies restoring force based on the elastic deformation of the mooring line. Due to high restoring stiffness taut mooring has high mooring lin tension which causes concerns.

The present analysis is mainly focused on 5 MW NREL wind turbine mode.

2. OFFSHORE WIND ENERGY:-

As mentioned earlier wind surrounding the globe has enormous potential to provide alternate source of energy in changing scenario where global energy demands are increasing by leafs and bounds. Wind turbine can be placed offshore or onshore but due to relatively low surface roughness of sea surface provides higher wind speed which places offshore wind turbine concept ahead of onshore wind turbine as per the volume of energy production is concerned . in the process of energy conversion wind energy from offshore wind turbine can be converted to electrical energy which can used in desired form of power supply.

Based on the water depth offshore wind turbine can be practically classified as

1- Swallow water wind turbine (5-30 meter)
2- Intermediate water wind turbine (30-60 meter)
3- Deep water wind turbine (more than 60 meter water depth).

As for as our present case is concerned the analysis is focused on intermediate water depth (50 meter) for which semisubmersible type floating offshore platform is one of the choice (others are tri floater , TLP) so entire analysis will be concerned on the analysis of floating offshore wind turbine supported by semisubmersible type floating offshore platform .

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2.1.CONCEPT SELECTION:-

After literature survey keeping the given sea state in mind and going through various features of different floating offshore platforms supporting floating offshore wind turbine conclusion was drown that TLP is best for given sea state which is in intermediate water depth range but considering cost factor semisubmersible is one of the choice so in present case it is taken as supporting platform .The semisubmersible type floating offshore platform selected in present scenario is 4 legged platform whose initial sizing and stability analysis will be mentioned further in the present discussion . Wind turbine selected for present case is NREL 5 MW floating offshore wind turbine whose specifications are given in the following table.

FEATURE	ATTRIBUTES
Rotor orientation, configuration	Upwind blades
Rotor, hub diameter	126 m , 3 m
Hub height	90 m
Cut in speed, cut out speed, wind speed	3 m/s , 11.4 m/s , 25 m/s
Max rotor speed	12.1 RPM
Rotor mass	80 m/s
Nacelle mass	110,000 kg
Tower mass	240,000 kg
Over all mass	347460 kg
Rating	5 MW

Table 1 : Wind turbine features and attribute

2.2. INITIAL SIZING:-

After selecting the concept model of the semisubmersible type floating offshore platform for supporting given NREL 5 MW wind turbine next step is to do initial sizing of the platform as per the wind turbine attributes and sea state. Sizing of the platform involves the following steps

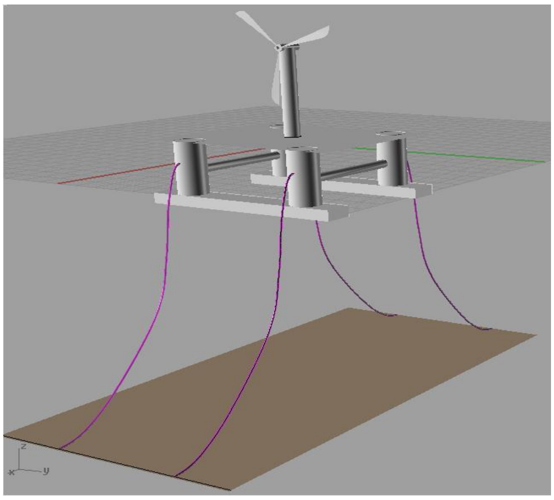

Figure 1. wind turbine model

Selection of characteristic dimensions of the platform by literature survey.

Then application of suitable loads which loading due to wind turbine and its subparts, environmental loading, loading due to deck etc. In case of small angle stability analysis as we know position of center of buoyancy changes subjected to the behavior of the platform in the water. Centre of buoyancy will be varying in me.

Now periodically varying column and pontoon dimensions so as to attain t

Attain the small angle stability based on the stability calculations.

In case of small angle stability analysis as we know Position of center of buoyancy changes subjected to the behavior of the platform in the water. Centre of buoyancy will be varying in same way as the draft decreases or increases due to variation in water displacement. And in case of small angle stability the center of buoyancy will move towards the side of the vessel which relatively more submerged. This corollary holds good for a unit in sea with Sufficient free board.

For small angle up to 10 degree the righting arm can be found out with the help of following formulae

$$GZ = GM * sin\alpha \qquad (1)$$

Where GZ = righting arm

GM = Meta centric height

2.3. STABILITY ANALYSIS :-

Suppose a system is floating in vertically upright condition then in that case the weight of the system acting through the center of gravity will be balanced by the force of buoyancy acting through the center of gravity, now imagine the system being heeled by a small angle say α then in such case center of buoyancy will be the geometric center of the underwater portion but since loading is still then in such case center of buoyancy will be the geometric center of the underwater portion but since loading is still the same center of gravity will not change and weight will be acting vertically downwards. so in nutshell we can say that the there will be 2 forces which will actually oppose each other, that is buoyancy and gravity force will form a couple whose magnitude can be given by the following formulae.

$$C = GZ * W \qquad (2)$$

Where C = magnitude of couple
GZ = liver arm
W = weight of the structure including its subparts

The line of action of force of buoyancy will meet the old force center line at certain point which will be referred as Meta center (M) and its distance from center of gravity will be designated as met centric height (GM).

If M lies above G the gravitational and buoyancy forces will act together to bring the ship in upright condition that is we can say that ship will be in stable equilibrium when M lies above G or GM is having certain positive value .

Generally the position of centers of gravity and buoyancy are measured with respect to the keel, and are given by following set of equations

$$BM = (I + Ah * h) / \nabla \qquad (3)$$

Now we know that the entire weight of the structure will act through the center of gravity (G) and the force of buoyancy through the center of gravity then if B, G positions with respect to the keel are KB and KG then these values can be given with the help of following set of formulae

$$KM=KB+BM \qquad (4)$$
$$GM=KM-KG \qquad (5)$$

After doing the stability analysis the size of semisubmersible obtained is as given in the following table

PART/COMPONENT	DIMENSION
Column diameter	7.5 m
Distance between column centers	34 m
Column length	23 m
Pontoon length	52.4 m
Pontoon width	7.5 m
Pontoon height	3 m
draft	13 m
Free board	10 m

Table 2 Semisubmersible dimensions

3. HYDRODYNAMIC ANALYSIS:-

The hydrodynamic analysis of the selected semisubmersible model supporting offshore wind turbine is done using ANSYS AQWA which basically uses PANEL METHOD for the analysis Panel method is discussed in detail as follow. The main numerical task to be performed in panel method is given by following methods

Define the potential function as

$$\varphi = \frac{ag}{\omega} * coshk(z + h)\sinh(kx - \omega t) \qquad (6)$$

Now divide the entire body into N number of source potentials and compute the local force and velocity functions for the each singularity point and then integrate them to find the global forcing function and by solving the equation of motion desired hydrodynamic properties can be obtained.

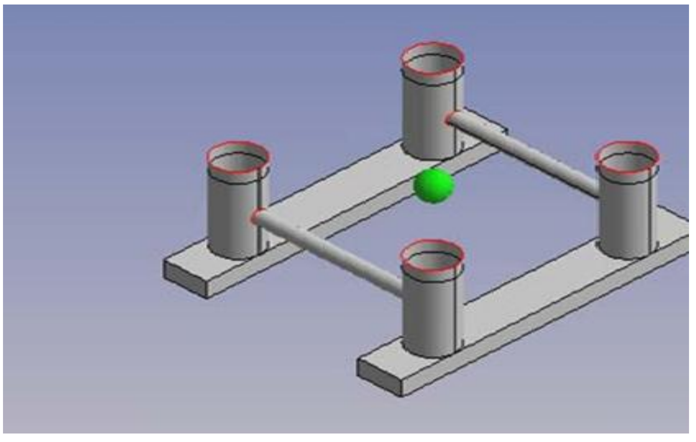

Figure 2ANSYS AQWA model of semisubmersible

The added mass, damping and excitation force values in panel method are obtained by solving the boundary value problem which deals the entire structure as shown in figure

First subpart will give the excitation force on the body , while second part will give added mass and damping value .

The assumption of potential flow defines the potential function and it satisfies Laplace equation

$$\nabla^2 \varphi = 0 \tag{7}$$

The linearization of problem permits the decomposition of velocity potential into radiation and diffraction components.

$$\varphi = \varphi D + \varphi R \tag{8}$$

First and term shows diffracted and radiated parts Respectively**.**

After doing hydrodynamic analysis using ANSYS AQWA which actually discretized the entire body into a number of panels and then calculated the source strength for individual panels and then integrated the source strengths to find out the overall source strength, hydrodynamic properties obtained are mentioned in the following table.

S NO.	PROPERTY	DESCRIPTION
1.	total displacement	4.84012E+03 m^3
2.	Position of COG	-10.405 m
3.	Position of center of buoyancy	-3 m

Table 3 Hydrodynamic Properties

Furthermore the small angle stability parameters are in the following table

S NO.	PROPERTY	DESCRIPTION
1.	BG	7.405 m
2.	GM_X	3.906 m
3.	GM_Y	3.906 m
4.	BM_X	10.501m
5.	BM_Y	10.501 m

Table 4 Stability Parameters

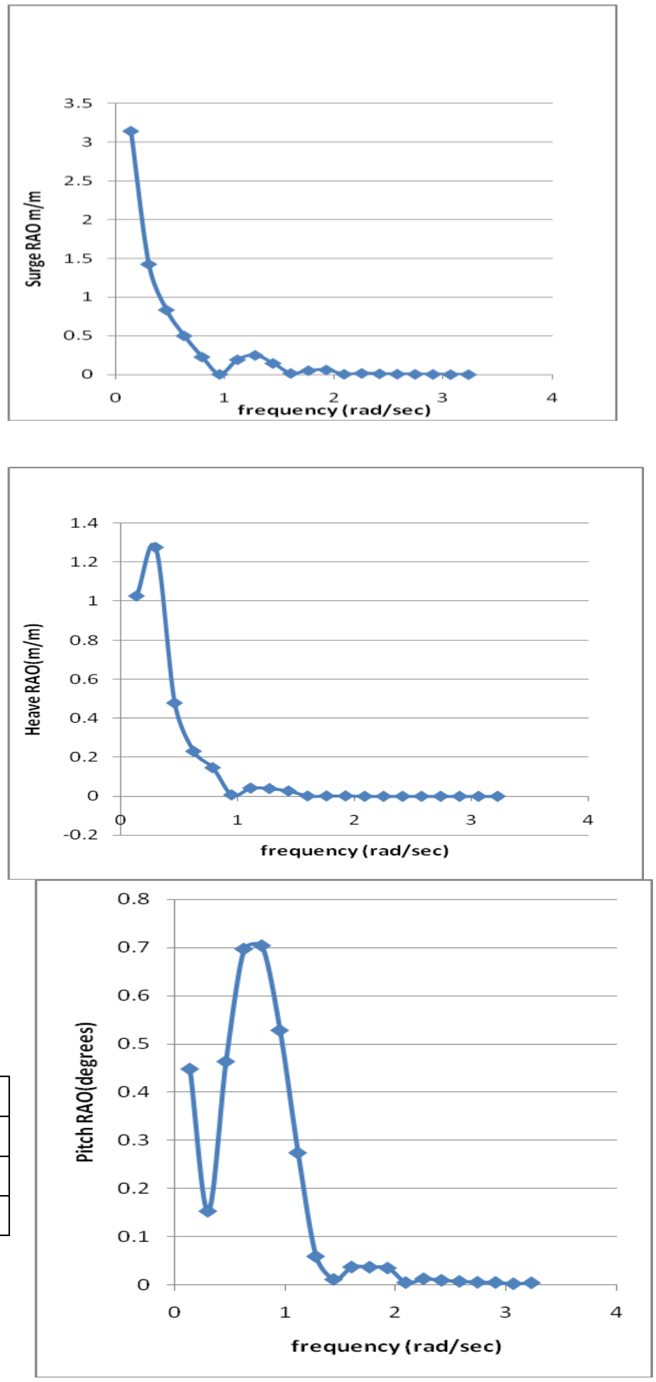

Figure 3 RAO of semisubmersible for 0degree wave heading

4. MOORING ANALYSIS:-

After obtaining the hydrodynamic properties and free floating RAO"s from ANSYS AQWA for mooring line analysis ORCAFLEX and AQWAGS software package is used. This software package uses centenary equation to analyze the mooring lines.

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The steps involved in the analysis can be summed up as follows

-Modeling of the semisubmersible type of structure in ORCAFLEX using line diagram method

-Now define the origin location (which is coinciding with the structure c.o.g in present case).

-Import the hydrodynamic data from ANSYS AQWA (ORCAFLEX will directly import the .lis file format).

-Now select the suitable mooring line configuration which is a catenary mooring line (4 in no) in present case connect it at a optimum location on the structure between centre of gravity and centre of buoyancy and connect the other end with the seabed with suitable azimuth angle and declination angle.

- Now run the static analysis and extract the mode shapes and fundamental frequency of the mooring lines for the given configuration.

After running the static analysis running dynamic analysis which gives the mooring line forces, RAO's added mass, damping values.

ORCAFLEX uses few terms in mooring line analysis which are discussed as follows

AZIMUTH ANGLE:-

Azimuth is the angle from X axis to the projection of the direction on the XY plane positive axis is therefore 0 azimuth angle and positive Y is 90 azimuth angle (right hand coordinate system).

DECLINATION ANGLE:-

Declination is the angle that direction makes with the Z axis. Therefore 0 is the positive Z direction and 90 is any Direction on the XY plane

STATIC ANALYSIS:-

Static analysis serves the following purposes-

- To define the equilibrium configuration of the structure under weight , buoyancy , hydrodynamic drag etc .
- To provide starting configuration for the dynamic analysis, as in most of the cases the static equilibrium configuration is the best one to start the dynamic simulation.

CATENARY ANALYSIS:-

While calculating the equilibrium position catenary analysis ignores the effect of bending and rotation in the line and on the ends. Catenary method includes following effects

-weight
-Buoyancy
-Axial stiffness
-Current drag
-Seabed touchdown

The complete description of the catenary theory is discussed in detail below.

The restoring forces and moments are mainly from changing the catenary shape.

Given figure shows the general arrangement of catenary line whose origin is fixed to its contact points to the sea bed and is given by (x_0, y_0, z_0).

The connection point to the sea bed is given by (x_m, y_m, z_m) , l_{eff} is the length of suspended catenary and d is the length lying on the sea bed or neutral length then overall catenary length can be given as

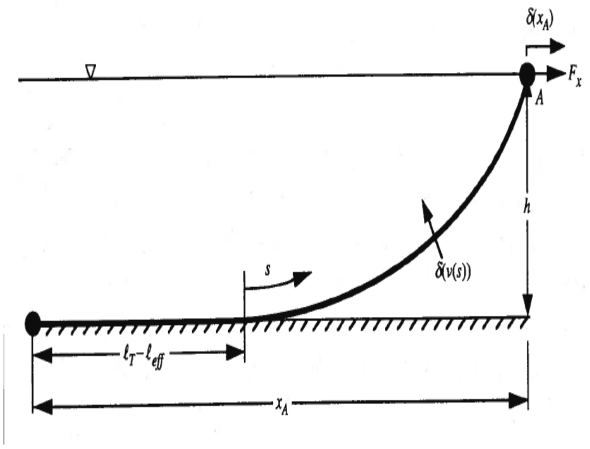

Figure 4 Catenary line details

$$L_T = l_{eff} + d \qquad (9)$$

Projected length of the suspended catenary can be given by the following equation

$$\frac{T_O}{P} * sinh(Pl/T_O)/T_O = \sqrt{h(h+2T_O/P)} \qquad (10)$$

Where T_0 is the horizontal tension and P is the vertical force per unit length, h is the water depth for given sea state , l is the distance of contact point to the connection point in horizontal direction . the solution of this equation can be obtained using Newton Rapson method . If l' is the total projected horizontal length then following relation holds good.

$$T - l' + l = \sqrt{h(h+2T_O/P)} \qquad (11)$$

The catenary line selected for the purpose of analysis in our case has following properties which are shown in the given table

S NO.	PARAMETER	VALUE
1.	Segment grade	R4S
2.	Nominal dia (m)	.13
3.	Length (m)	90
4.	O.D (m)	.234
5.	Contact dia(m)	.4355
6.	Mass/length (kg/m)	293
7.	Axial stiffness (N/m)	9.0E9

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8.	Axial added mass coefficient	.07
9.	Normal added mass coefficient	1
10.	Axial drag dia(m)	.0223
11.	Normal drag coefficient	1
12.	Axial drag coefficient	.273
13.	Normal drag dia(m)	.4
14.	Allowable load (N)	20E4

Table 5 Chain Mooring details

After analysis of the entire system of wind turbine supported to the semisubmersible and with the connected mooring lines the values of the forces on the mooring line ends and various properties of the system are shown in the given table the simulation has been run for the moored system of semisubmersible platform supporting offshore wind turbine which will give the variation of centre of gravity position and mooring forces in axial and rotational directions describing a particular band of values within which these will vary for given moored system.

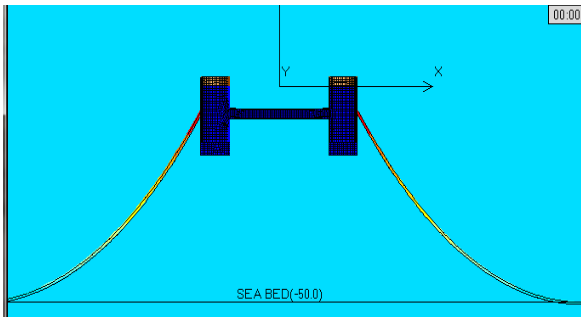

Figure.5 AQWAGS image of moored semisubmersible

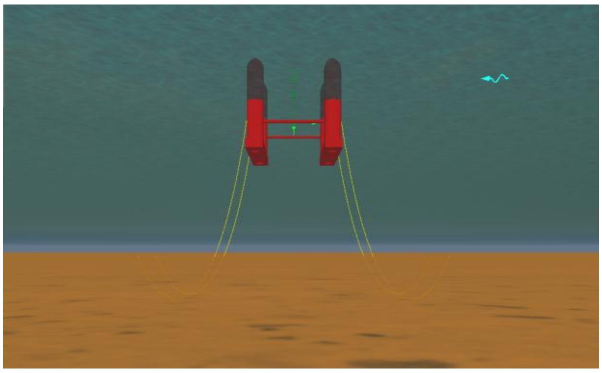

Figure. 6 ORCAFLEX image of moored semisubmersible

The moored system of semisubmersible platform is analyzed in AQWAGS and the variation of center of gravity of the moored system is varying in axial and rotational direction are as shown in following graphs.

The graphs indicates the pattern or range of the values within which the centre of gravity of the moored system of semisubmersible will lie for the continuation of the motion.

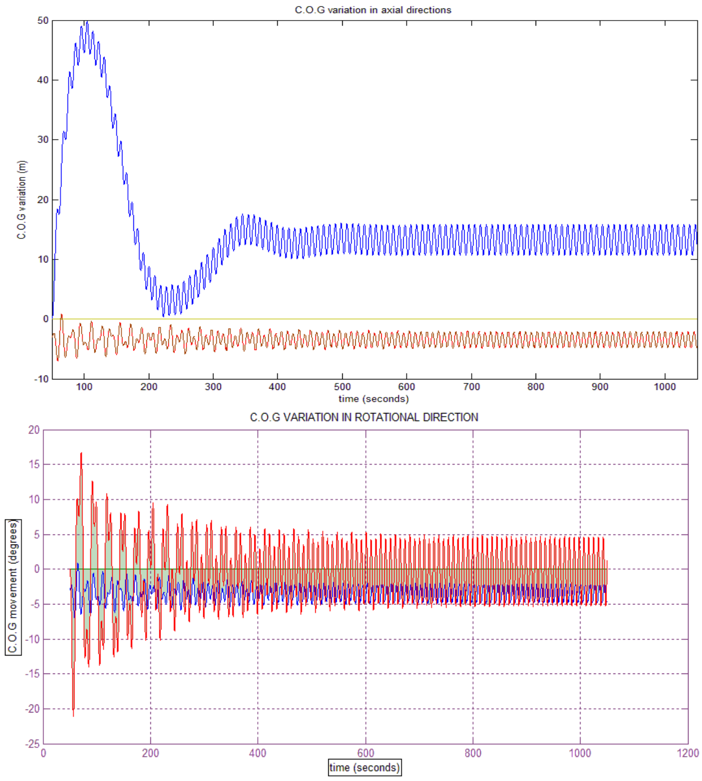

Figure 5 COG variation in axial and rotational directions

The variation of mooring forces in axial and rotational direction for the catenary mooring lines used are shown in following graphs

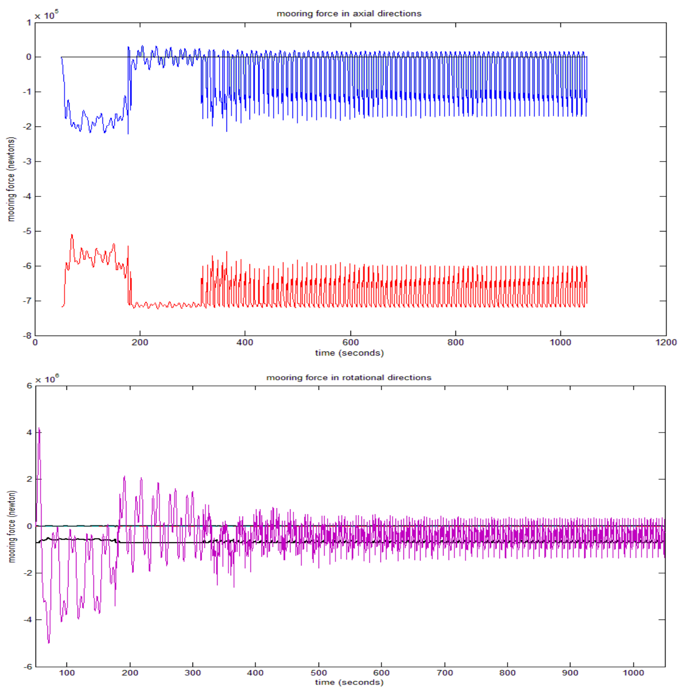

Figure 6 Mooring force variation in axial and rotational directions

The mooring forces are having large magnitude in x and y directions as compared to the vertical direction Since the mooring lines are placed symmetrically with respect the variation of mooring line tension along the arc length for all segments of mooring line are shown in the graph as follows.

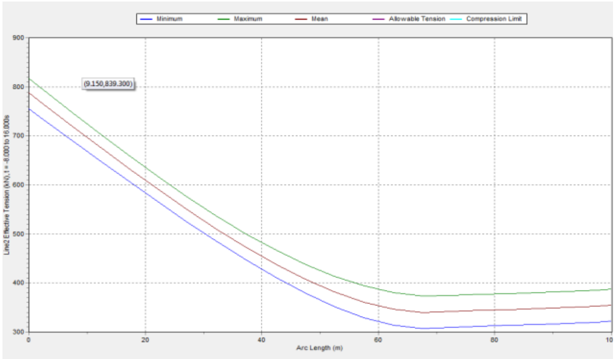

Figure 7 Tension along the mooring line

The plot clearly indicates that the mooring tension is highest at the joint of it with the structure and varies to the point when line reaches its neutral length value and after that almost remains constant till the anchor point. It also signifies that the tension in the mooring line is dependent on the orientation of the line and variation of tension along the length depends on projected length and neutral length.

4. CONCLUSION:-

In nutshell the present analysis gives a detailed description of the behavior of wind turbine on semisubmersible type platform both in free floating and moored condition and gives the range within which the centre of gravity and mooring forces varies along all 6 degrees of freedom. After attaching the mooring lines the RAOs will be redefined and motion of the structure will be confined in a suitable range as shown in plots of COG movement. The analysis signifies that the response of the system with mooring lines can mainly be altered in x and y directions but vertical movement will not be affected. The hydrodynamic analysis signifies that by refining the panel size the results can be further modified. The results can be further modified by changing the mooring configuration or by increasing the number of mooring lines.

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