ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

MODELING OF SPAR-TYPE FLOATING OFFSHORE WIND TURBINES

M.Sc. THESIS

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Department of Ocean Engineering
Shipbuilding & Ocean Engineering Programme

Anabilim Dalı : **Herhangi Mühendislik, Bilim**
Programı : **Herhangi Program**

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Thesis Advisor: Assis. Prof.Ayhan MENTES

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

SPAR TİPİ AÇIKDENİZ RÜZGAR TÜRBİNLERİ MODELLENMESİ

YÜKSEK LİSANS TEZİ

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OCAK 2015

M.Sc. or Ph.D.

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To my family,

FOREWORD

I would like to express my sincere gratitude to all of the following people who always encouraged me to work on this subject.

First of all, I would like to express my deep appreciation and thanks to my advisor Assis. Prof. AyhanMentes for his continuous help and efforts.

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January 2015 Nagihan TURKOGLU

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ABBREVIATIONS

ANN : Artificial Neural Network
CAE : Computer Aided Engineering
CO2 : Carbon Dioxide
DOF : Degree of Freedom
HAWT : Horizontal-axis wind turbines
NREL : National Renewable Energy Laboratory
NWTC : National Wind Technology Center
OFWT :Offshore Floating Wind Turbine
RPM : Revolutions Per Minute
VAWT : Vertical-axis wind turbines

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MODELLING OF SPAR-TYPE FLOATING OFFSHORE WIND TURBINES

SUMMARY

Most of countries in the world currently rely on coal, oil and natural gas for their energy. The fact that fossil fuels are non- renewable and finite resources therefore they are becoming too expensive. Other important point about fossil fuels is they damage environment. On the other hand, so many renewable energy resources are infinite and friendly to the environment.

Solar, wind, wave, geothermal, hydrogen, tidal and bioenergy are some important renewable energy resources. Geothermal energy taps the Earth's internal heat for a variety of uses, including electric power production, and the heating and cooling of buildings. Tidal energy of the ocean's tides come from the gravitational pull of the moon and the sun upon the Earth. Hydrogen also can be found in many organic compounds, as well as water. Wind energy is using wind turbines to produce electrical power.

In thıs thesis, Spar type wind turbine modelled with the couple of the OrcaFlex and FAST softwares for getting amount of displacement and rotation. Using result of simulation, problem modelled with artificial neural network.

In the second part of the thesis, wind turbines are discussed. History of wind turbine is stayed in this chapter. It is clearly observed that principles of operation and wing shapes of wind turbines change by year. Therefore there are two classification about wind turbines; types of wind turbines and foundation of wind turbines.

In the third part of study, Software programs are introduced. Moreover, information about artificial neural network is given in this part. Orcaflex is friendly simulation program for offshore structers. Offshore structure modelling is easy with it. Therfore it has wide application area for ocean technologies. FAST uses Fortran for simuluating wind turbine model. It gives aerodynamic and hydrodynamic results for them.

In the next chapter, Spar type wind turbine is modelled with FASTlink and artificial neural network. The simulations are performed in different environmental conditions which are affected by the wind speed, wave height, water depth and current velocity variables. Simulation cases are grouped according to number of mooring lines so there are three different cases in the simulation studies. Neural network fitting tool in MATLAB is used for modelling of the problem in this wind turbine.

Finally, conclusion about the thesis and recommendations for future study are given at in this chapter.

SPAR TİPİ AÇIK DENİZ YÜZER RÜZGAR TÜRBİNİ MODELLEMESİ

ÖZET

Dünya nüfusunun artışı ve teknolojik gelişmeler ile birlikte doğal kaynakların günden güne tükenmesi insanlığı alternatif çözümler aramaya sevk etmiştir. Bu sebeple yenilenebilir enerji kaynaklarının kullanımı ve bu alandaki teknolojik gelişmeler hız kazanmıştır.

Yenilenebilir enerji kaynakları denildiğinde akla ilk gelen güneş enerjisi olsa da ciddi kazanımlar sağlayan başka kaynaklar da mevcuttur.Bunları rüzgar enerjisi, dalga enerjisi, jeotermal enerji, gel git akıntılarından elde edilen enerji şeklinde sıralamak mümkündür.

Yenilenebilir enerji kaynakları kullanımının yaygınlaşmasındaki bir diğer sebep insanlarda çevre bilincinin oluşmasıdır. Temiz enerji temiz bir dünya sloganı ile başlayan bu aydınlanma yenilenebilir enerji teknolojisine yatırımların artmasına olanak sağlamıştır.

Bu alanlarda yapılan teknojik buluşlar kısa süreli bakıldığında çok maliyetli görünse de uzun vadede kazançlı bir yatırım olmaktadır. Güneş enerjisinden yararlanma oldukça yaygınlaşmıştır. Güneş enerjisi ile çalışan arabalar, yatlar üretilmiştir. Bunun yanı sıra güneş enerjisinin evlerde kullanımı oldukça yaygındır. Dalga enerjisi ve gel-git olayından elde edilen enerji ile ilgili çok fazla sayıda çalışma da mevcuttur.

Rüzgardan enerjisinin kullanımı çok eski zamanlara dayanmaktadır. Rüzgar gülü ile başlayan ve günümüzde rüzgar tarlalarının kurulmasına kadar gelen süreçte önemli gelişmeler olmuştur. Karada kurulan rüzgar türbinleri ve tarlalarının yanısıra daha çok enerji sağlayacak okyanuslarda rüzgar tarlalarının kurulması çalışmaları hız kazanmıştır.

Bu çalışmanın amacı, SPAR tipi bir rüzgar turbine modellemesini OrcaFlex ve Fast programlarını kullanarak gerçekleştirmek, elde edilen öteleme ve dönme hareket miktarlarını yapay sinir ağları algoritmasını kullanarak modelleyebilmektir. Sinir ağları ile düzgün bir modelleme yapıldığında OrcaFlex ve Fast programlarına ihtiyaç duyulmadan bu tip platformların hareketlerini değişik çevre şartları altında hesaplamak mümkün olacaktır.

Tezin ikinci bölümünde rüzgar türbinleri ele alınmıştır. Yüzer rüzgar türbinlerinin tarihi incelenmiştir. Yıllara oranla türbinlerin çalışma prensipleri ve kanat şekillerinde değişimler görülmektedir. Bu sebeple rüzgar türbini çeşitlerine yer verilmiştir. Bunun yanısıra türbinlerin kurulma alanlarına göre de sınıflandırma yapılabilir. Karada ve açık denizlerde kurulan farklı tipte türbinleri bulunmaktadır. Her ne kadar yeni bir teknoloji olsa da yüzen yapıların üzerine kurulan spar tipi yarı batık ve gergi ayaklı türbin çeşitleri mevcuttur.

Üçüncü bölümde tezde kullanılan yazılımlar tanıtılmıştır. Bunun yanı sıra yapay sinir ağlarının tanımı, çalışma prensibi ve kullanıldığı alanlardan bahsedilmiştir. Orcaflex açıkdeniz yapılarının modellenmesi ve dinamik analizlerinin yapılmasına olanak sağlayan bir programdır. Çok geniş uygulama alanlarına sahiptir. Fast, Fortran dilinde yazılmış, rüzgar türbinlerinin modellemesi yapılabilen bir programdır. İki veya üç kanatlı türbinlerin tüm aerodinamik ve hidrodinamik analizleri yapabilmektedir.Fastlink ise Orcaflex ve FAST programının entegre çalıştığı bir programdır. Orcaflex kullanıcısı tarafından yüzer rüzgar türbini analizleri için yazılmış olup Spar ve TLP örnek uygulamaları mevcuttur. Kullanılacak olan açık deniz yapısının hidrodinamik analizleri Orcaflex'te gerçekleşmektedir. Aerodinamik hesaplamaları ise FAST yapar. Orcaflex'ten sonuçlar alınır ve sonuç dosyası FAST tarafından oluşturulur

İlk yapay sinir ağı modeli 1943 yılında, bir sinir hekimi olan Warren McCulloch ile bir matematikçi olan Walter Pitts tarafından gerçekleştirilmiştir. Yapay sinir ağları (YSA), insan beyninin özelliklerinden olan öğrenme yolu ile yeni bilgiler türetebilme, yeni bilgiler oluşturabilme ve keşfedebilme gibi yetenekleri, herhangi bir yardım almadan otomatik olarak gerçekleştirebilmek amacı ile geliştirilen bilgisayar sistemleridir.

Yapay sinir ağları gerçekte var olan problemlerin çözümünde sıklıkla kullanılmaktadır. Uygulama alanı çok geniştir. Yapay sinir ağlarının tercih edilme nedenlerinden biri, eksik veriler olsa dahi iyi sonuçlar vermesidir. Bir diğer avantajı ise öğrenmenin tamamlanması ile sadece girdiler ile sağlıklı sonuçlar elde edilmesidir.

Tezin dördüncü bölüm uygulama kısmının yer aldığı bölümdür. Yüzer rüzgar türbini çeşitlerinden olan SPAR tipi rüzgar türbini Orcaflex ve FAST programının ortak bir ürünü olan FASTlink programı kullanılarak modellenmiştir.. Spar'ın en önemli özelliği stabilitesini balast ile sağlıyor olmasıdır. Deniz dibine bağlayan halatlar gergin veya gevşek halde olabilirler. Bu çalışmada halatlar gevşek olarak bırakılmıştır. Yüksek gerilmeleri önlemek için halat boyu uzun tutulmuştur. Bu sebeple halat ağırlıkları büyük değerlere sahiptir.

Spar tipi rüzgar türbini için üç farklı bağlama sistemi kombinasyonu düşünülmüştür. Uygulamada 2 farklı akıntı değeri, 4 farklı rüzgar hızı ve 4 farklı değerde dalga yüksekliği parametreler olarak belirlenmiştir.

Birinci kombinasyonda rüzgar türbüni uç noktalı bağlama sistemi ile modellenmiştir. Akıntı değeri sabitlenip rüzgar ve dalga parametrelerinde değişiklik yapmak koşulu ile FASTlink programında analizler yapılmıştır. Elde edilen sonuçların tutarlı olup olmadıkları incelendikten sonra aynı işlemler dört noktalı ve altı noktalı bağlama sistemi için uygulanmıştır.

Analizler tamamlandıktan sonra x,y,z yönündeki yer değiştirme ve dönme miktarları hesaplanmıştır. Aynı parameter değerleri kullanılarak yapılan farklı bağlama sistemlerindeki sonuçlar bir biri ile karşılaştırıldığında bağlama sistemindeki halat sayısının artışı ile Spar tipi rüzgar türbininin dönme ve yer değiştirme miktarlarında azalma gözlemlenmiş ve yapının denge durumunun iyileştiği sonucuna varılmıştır. Bu aşamadan sonar elde edilen veriler doğrultusunda tezin ikinci kısmını oluşturan yapay sinir ağları modellemesine geçilmiştir.

Bu çalışmada spar tipi rüzgar türbininin yapay sinir ağları ile modellenmesi Matlab programının Neural Network Fitting eklentisi ile yapılmıştır. Programa girdi bilgileri olarak hidrodinamik analizlerde kullanılan rüzgar dalga akıntı dalga periyodu parametreleri verilmiştir. Hedef olarak ise analizlerden elde edilen, platformun x,y,z yönlerindeki yer değiştirme ve dönme miktarları girilmiştir.

Yapay sinir ağlarından elde edilen sonuçların daha sağlıklı olabilmesi için birden fazla iterasyon yapılmıştır. Uygulamada nöron sayısı değiştirilerek daha hassas bir sonuç elde edilmesi amaçlanmıştır.

Yapay sinir ağlarından elde edilen sonuçlar ile FASTlink'den elde edilen sonuçların örtüştüğü gözlenmiştir. Yapay sinir ağları modellemesi 3 farklı bağlama sistemine de başarılı bir şekilde uygulanmıştır.

Son bölümde ise, tezin başlangıcında yapılmak istenen ve tez bitiminde ulaşılan hedeflerden bahsedilmiştir. Tezde kullanılan tüm programlar ve yapay sinir ağları ile ilgili devam eden çalışmalar hakkında bilgi sahibi olunmuştur. Bunun yanında kullanılan programlar ihtiyaç doğrultusunda öğrenilmiş modellenen platform doğru sonuçlar vererek başarılı olmuştur. Elde edilen yapay sinir ağı modeli ile farklı girdiler girerek analiz yapmaya gerek kalmadan istenen sonuçlar alınabileceği gözlemlenmiştir. Yine bu bölümde gelecek çalışmalar için tavsiyelerde bulunulmuştur.

1. INTRODUCTION

It is a known fact that fossil fuels are used frequently in various fields in the industry. Nowadays, it is clearly observed that fossil fuels are finite power resources and they cause environmental pollution and green house effect. On the other hand, renewable energy sources such as wind, solar,geothermal, hydroelectric, and biomass energies provide a better option for climate, human health and economic aspects.

Renewable energy resources can be used to generate electricity without producing CO_2 therefore they are friendly for environment. Wind power is an example of clean energy sources that can be relied on for the long-term operability.Wind turbines are one of the most efficient renewable energy devices that have been created due to their low emissions and high efficiency. A wind turbine creates reliable, cost-effective, pollution free energy that can be used for any purpose in the industry and also in the city life due to its affordable, clean and sustainable nature.

Wind power is a consistent type of energy for long time investments, but it has significant variations over shorter time periods. When the demand of wind power in a region increases, one needs to upgrade the energy grid and increase the storage capacity and optimize the efficiency in that area.

In order to alleviate the drawbacks of the onshore wind energy production, engineers constructed offshore wind farms to provide large scale energy. These installations can be utilized close to each other and with the aid of powerful winds that are available in the pre-defined locations have less aesthetic impact on the nature than the onshore wind farms. On the other hand, offshore wind farms have elavated cost in the construction and the maintenance fields.

1.1 Aim of Thesis

Investigating the response of a SPAR type floating wind turbine under extreme environmental conditions.

Investigation previous studies for floating wind turbines.
Getting information about OrcaFlex and Fast programs.
Modelling Floating Wind Turbine by using OrcaFlex and Fast porgrams.
Forecasting the response of a spar type wind turbine by using Neural Networks.

2. WIND TURBINES

2.1 History of Wind Turbine

The first wind mills, were placed in Persia, and used around 200 BC.However first functional wind mills were built in Sistan an Eastern district of Iran. These wind mills were used to provide water and process sugarcane (Hassan and Hill,1986).

The first known wind turbine was installed for electricity production in 1887. The turbine is created by James Blyth in Marykirk, Scotland. Throughout the 20th century, small wind plants, suitable for farms and residences, and larger utility-scale wind farms that could be connected to electricity grids were developed.

The oil shortages of the 1970s changed the energy picture for the U.S. and the world. It created an interest in alternative energy sources, paving the way for the re-entry of the wind turbine to generate electricity.

While wind energy’s growth in the U.S. slowed dramatically after tax incentives ended in the late 1980s, wind energy continued to grow in Europe, in part due to a renewed concern for the environment in response to scientific studies indicating potential changes to the global climate if the use of fossil fuels continues to increase.

Today, wind-powered generators operate in every size range, from small turbines for battery charging at isolated residences to large, near-gigawatt-size offshore wind farms that provide electricity to national electric transmission systems. Moreover Danish Company Vestas is the world's biggest wind-turbine manufacturer.

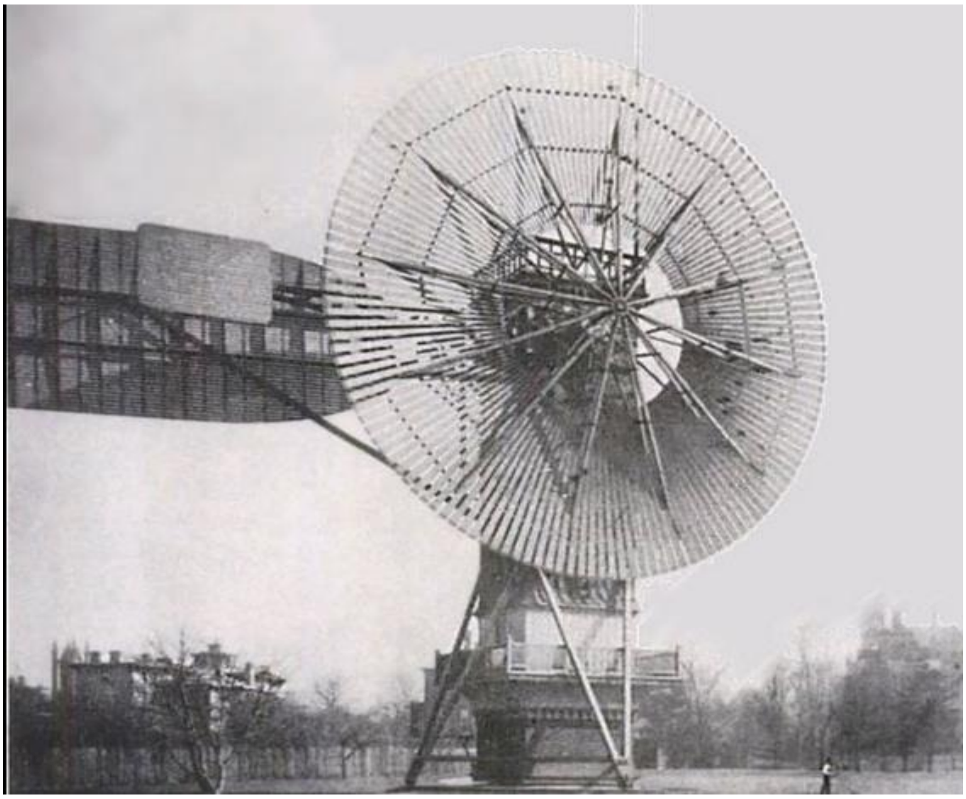

Figure 2.1 : First Windmill.

2.2 Types of Wind Turbine

There are mainly two types of wind turbine. Horizantal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) are which are classified with respect to themotion of their shaft axis.

2.2.1 Horizantal axis wind turbine

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbines are pointed by a simple wind vane placed square with the rotor blades, while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind.

Large scalewind turbines have a gearbox, which increases the speed of the rotor from slow to fastrotation which increases the efficiency of the electric generator.

Figure 2.2 : Horizantal Axis Wind Turbine.

2.2.2 Vertical axis wind turbine

The verticalaxis wind turbines have the main rotor shaft constructedvertically. The main advantage of this arrangement is that the wind turbine does not need to be adjustedinto the wind direction. This is an advantage on sites where the wind direction is highly variable or has turbulent winds.

In the vertical axis wind turbine, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier.

Figure 2.3 : Vertical Axis Wind Turbine.

2.3 Foundation of Wind Turbine

Wind turbines can be built on onshoreor offshore depending on the energy needs. Offshore wind turbines are applied generally in oceans and lakes.

Figure 2.4 : Wind Farm; Onshore (right) and Offshore (left).

2.3.1 Land-based wind turbine

There are four main partswhich constitute a wind turbine namely: the base, tower, nacelleand blades. The blades capture the wind and spina generator in the nacelle. The tower contains the electrical conduits, supports the nacelle and provides access to the nacelle for maintenance. The base is generallymade of concrete and steel in order to maintain the structural integrity of a wind will.

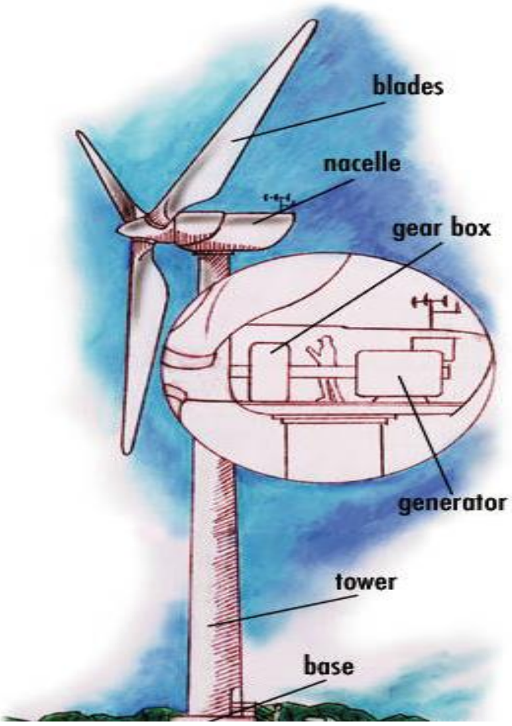

Figure 2.5 : Land Based Wind Turbine.

2.3.2 Floating Wind Turbine

Floating wind turbines have used since 1970. However,there have been researches conducted since in the mid of the 1990s.

First floating wind turbine was built in Italian coast in 2008. Nowadays, in offshore wind farms three main types of deep offshore foundations are used, which are originally adapted from the offshore oil and gas industry.

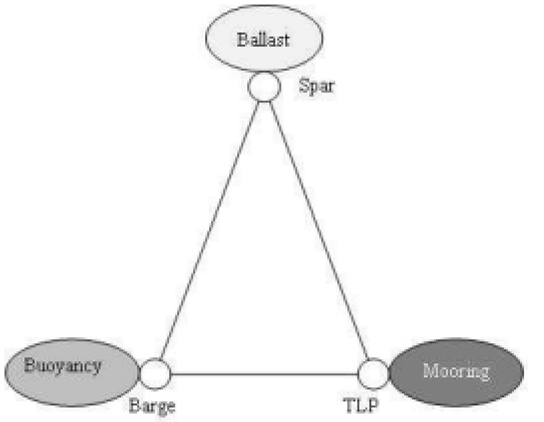

Figure 2.6 : Static Stability Method (Jonkman,2007).

2.3.2.1 Spar buoy

The Spar-buoy type wind turbine uses ballast load to lower the centre of gravity below thecentre of buoyancy to maintainthe stability of the wind turbine. In general they are moored by catenary or taut lines.A spar buoy is a very long cylinder platform protruding out of the mean water surface. The wind turbine is installed on top of this cylinder. The cylinder needs to be ballasted enough to lower the centre of gravity below the centre of buoyancy in order to achieve stability. The buoyancy force will be in balance with the gravity force and the restoring is achieved by means of the vertical distance between the centres of buoyancy and the gravity. The spar buoy will also be equipped with mooring lines for station keeping. The location of fair lead position of the mooring lines is critical. (Ramachandran,2012)
A typical example of Spar buoy type is the Hywind concept, developed by Statoil Hydro,Norway.

2.3.2.2 Tension leg platform

TLP achieves stability through the pretension in the tension legs. Since the structure is having positive buoyancy, the additional buoyancy needs to be balanced by applying equal pretension in the mooring lines to achieve stability. Ballasting can also be used partly to achieve stability. One of the such types is the Blue H concept, installed in Italian waters.(Ramachandran,2012)

2.3.2.3 Barge

Barge concept is stabilised through its water plane area and generally moored by catenary lines.

It is a shallow-drafted platform. Some ballasting may be required to achieve the desired draft. Mooring lines are used for station keeping purpose. Since the platform has sufficient restoring without the mooring lines, it is easier to assemble the platform with the wind turbine and float it out to the location of installation (Ramachandran,2012).

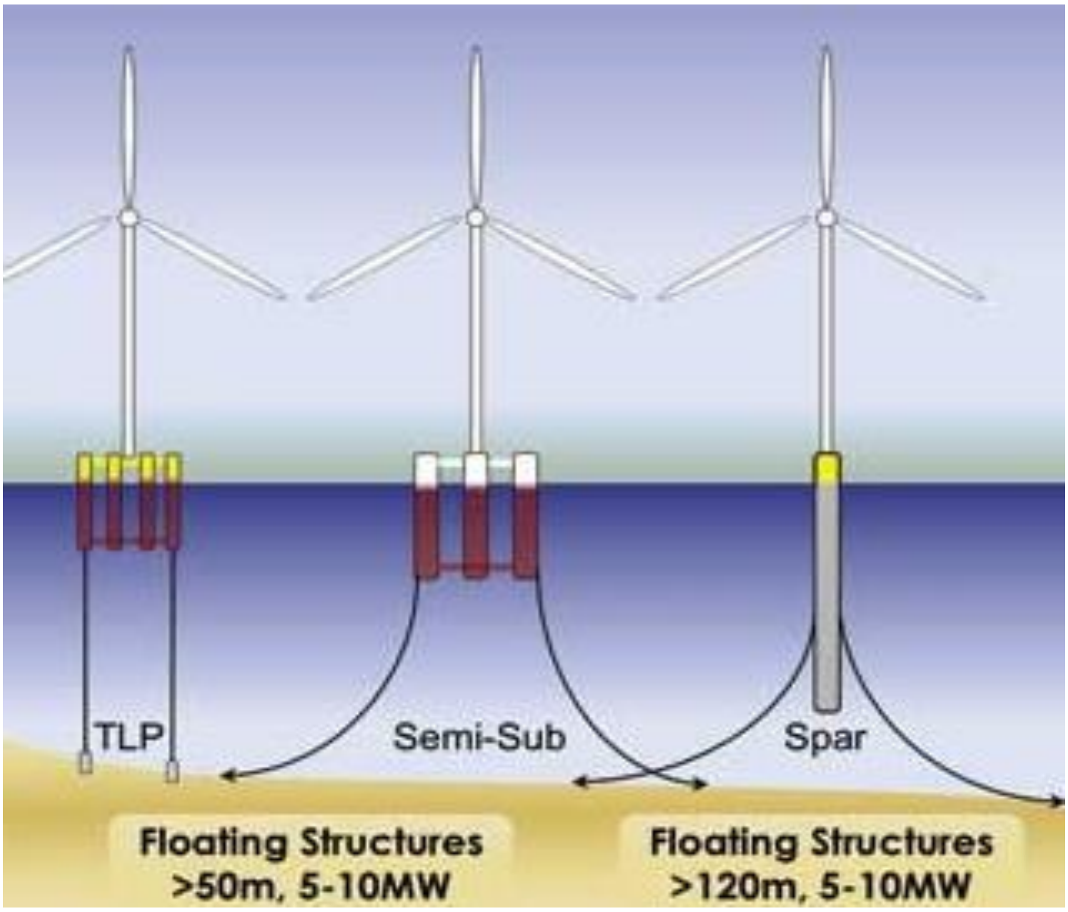

Figure 2.7 : Floating Wind Turbine.

2.3.3 Floating wind turbine properties

Anchors

Based on the applications and load carrying capacity, there are different anchoring systems available such as gravity based, drag embedded, driven pile, suction, drilled and grouted and torpedo embedded anchors. The right one needs to be selected based on the soil conditions, which determine the load capacity of the anchors. Out of these, the vertically loaded anchors are more expensive due to their deep embedment in order to maximize the pull out load.

Mooring system

Based on the mooring system, the floating offshore wind turbine structures can be classified as catenary mooring, taut leg mooring and tension leg mooring systems. Examples of concepts that utilize catenary mooring systems are spar buoys, tri-floater concept, pill box design etc.Vertical tension leg is a sub set of taut leg system.

Material selection

Research is still being done on the selection of floater material. Concrete and steel are the conventional materials, however, a cost effective solution is still being finalized.

Environmental Conditions

Deep water wind turbines are subjected to complex combination of wind, wave and current loading. The wave loading is basically nonlinear and three dimensional in nature. There are a number of theories, which describe the wave loading based on the environmental conditions, wave steepness, slenderness of the structure under wave loading.

Table 2.1 : Design Challenge Tradeoffs for Stability Criteria (Jonkman, 2007).

	Floating Platform Technical Challenges Platform Stability Classifications		
Platform Design Challenge	Buoyancy (Barge)	Mooring Line (TLP)	Ballast (Spar)
Design Tools and Methods	-	+	-
Buoyancy Tank Cost/Complexity	-	+	-
Mooring Line System Cost/Complexity	-	+	-
Anchors Cost/Complexity	+	-	+
Load Out Cost/Complexity (potential)	+	-	
Onsite Installation Simplicity (potential)	+	-	+
Decommissioning & Maintainability	+	-	+
Corrosion Resistance	-	+	+
Depth Independence	+	-	-
Sensitivity to Bottom Condition	+	-	+
Minimum Footprint	-	+	-
Wave Sensitivity	-	+	+

Key:

+ = relative advantage
- = relative disadvantage
blank = neutral advantage

3. ANALYSIS SOFTWARE

3.1 Orcaflex

OrcaFlex is the world's leading commercial softwarefor the dynamic analysis of offshore marine systems, acknowledged withits technical capability and user friendliness. OrcaFlex also has aunique capability in its class to be used as a library, allowing a host of automation possibilities and ready integration into 3rd party software (Orcina,2014).

OrcaFlex is in use by over 260 clients, mainly in the offshore engineering business, with others in seismic, defence, ocean engineering, oceanographic research, aquaculture, compliant marine renewable and related fields. (Orcina, 2014)

OrcaFlex has a very wide range of applications;

Risers	Moorings	Installation Analysis
Buoy System	Hose System	Towed System
Defence	Renewable Energy	Miscellaneous

OrcaFlex builds and analyses a mathematical model of the system, The mathematical model isbuilt up from a series of interconnected objects, such as lines, vessels and buoys. Figure 3.1 illustratesflowchart of the the sequence of states which is used and the actions, results etc. available in each state.

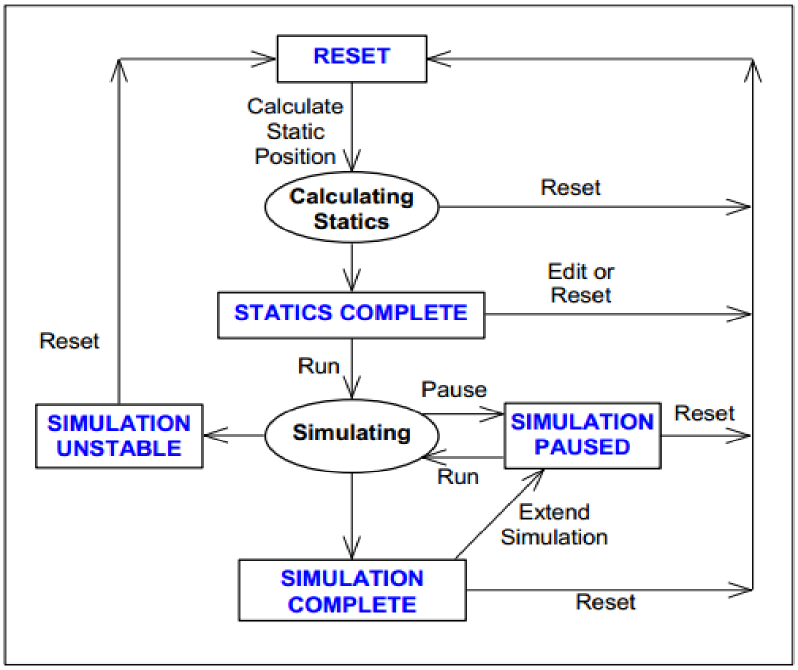

Figure 3.1 : Modal State (Orcina,2014).

3.2 FAST

NREL has sponsored the development, verification and validation of various Computer-Aided Engineering (CAE) tools for prediction of wind-turbine loads and responses. FAST, can be used to model both two and three-bladedhorizontal-axis wind turbines.

The FAST code models the wind turbine as a combination of rigid and flexible bodies. The rigid bodies are the earth, nacelle, hub, and optional tip brakes (point masses) while the flexible bodies include blades, tower, and drive shaft. The model connects these bodies with several DOFs in the system solutions. These include tower bending, blade bending, nacelle yaw, rotor teeter, rotor speed, and drive shaft torsional flexibility (NREL, 2014).

FAST uses Kane's method to set up equations of motion, which aresolved bythe aid of numerical integration. The implemented method makes direct use of the generalized.

3.3 FASTlink

The couple of the OrcaFlex and FAST softwares simulatethefloating wind turbine systems. In this coupling, FAST is responsible for capturing the aerodynamic loads, the turbine control system, the platform global motion and flexure of the wind turbine and its tower,and OrcaFlex models the mooring line and hydrodynamic effects below the water surface. (Jonkman, 2009)

In the FASTlink coupling module, FAST outputs the vessel position and velocity vectors into OrcaFlex.Line tension and hydrodynamic added mass matrix and velocity dependent hydrodynamic forces are calculated by OrcaFlex; the resulting added mass matrix ,total force and moment on the platform is passed back into FAST; then the resulting platform motion is solved in FAST (Jonkman, 2009).

The FASTlink coupling module was developed by Orcina,in collaboration with industrial partners.

3.4 Artificial Neural Network

Artificial Neural Networks (ANNs) are part of computer technology insipired by the brain activity which is called biological neural networks. Basically,they are used to estimate results of the problem.

Natural neurons receive signals through synapses located on the dendrites or membrane of the neuron. When the signals are receivedstrong enough to surpass a certain threshold, the neuron is activated and transportsa signal though the axon. In the next step,this signal might be sent to another synapse, and might activate other neurons.

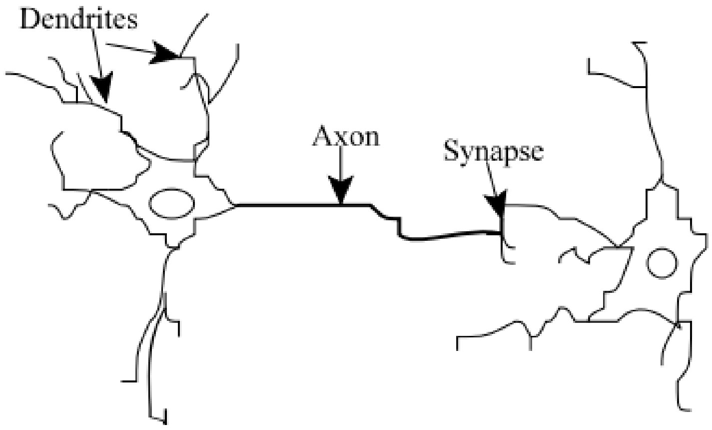

Figure 3.2 : Natural Neurons.

Artificial Neural Networks act like biological neural networks. The mathematical modelof the artificial neurons are very simple. System consist of inputs (like synapses), which are multiplied by weights (strength of the respective signals), and then computed by a mathematical function which determines the activation of the neuron. Another function ,which may be the identity, computes the output of the artificial neuron (Gershenson,2003).

The neurons are connected to different layers. The input layer receives the input, the output layer produces the results. In general,there are one or more hidden layers between the two. This structure makes it impossible to predict or know the exact flow of data.

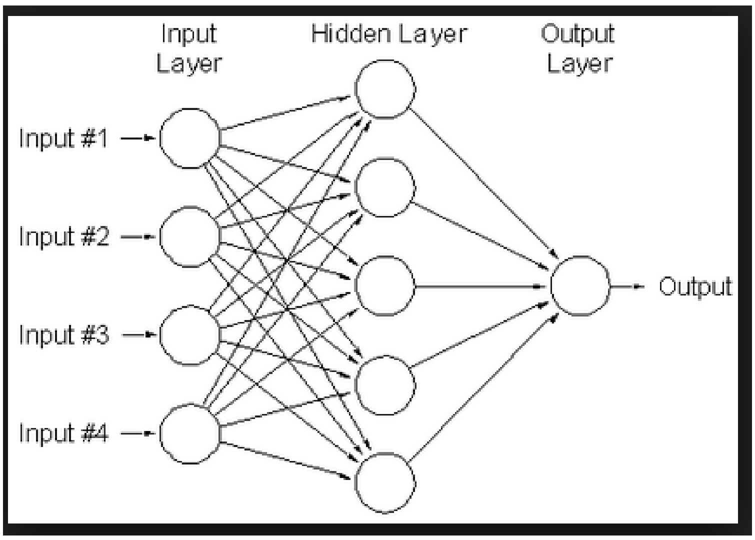

Figure 3.3 : Artificial Neural Network (Gershenson,2003).

3.4.1 Learning

There are three major learning paradigms namely:supervised, unsupervised and reinforced learning. Usually they can be employed by any given type of artificial neural network architecture. Each learning paradigm has many training algorithms and they are explained in detail in the next sessions

3.4.1.1 Supervised learning

Supervised learning is a machine learning technique which uses the parameters of an artificial neural network from training data. The task of the learning artificial neural network is to set the value of its parameters for any valid input value after the following output value. The training data consist of pairs of input and desired output values that are traditionally represented in data vectors. Supervised learning can also be referred as classification, where we have a wide range of classifiers, each with its strengths and weaknesses (Krenker& Kos,2011).

Choosing a suitable classifier (Multilayer perceptron, Support Vector Machines, k-nearest neighbour algorithm, Gaussian mixture model, Gaussian, naive Bayes, decision tree, radial basis function classifiers,…) for a given problem is however still more an art than a science. (Krenker& Kos, 2011)

3.4.1.2 Unsupervised learning

Unsupervised learning is a machine learning technique that sets parameters of an artificial neural network based on given data and a cost function which needs to be minimized. Cost function can be any function and it is determined by the task formulation. Unsupervised learning is mostly used in applications that fall within the domain of estimation problems such as statistical modelling, compression, filtering, blind source separation and clustering(Krenker&Kos,2011).

3.4.1.3 Reinforcement learning

Reinforced learning is also a machine learning technique that sets parameters of an artificial neural network, where data is usually not given, but generated by interactions with the environment(Krenker&Kos,2011). Reinforced learning is concerned with how an artificial neural network ought to take actions in an environment so as to maximize some notion of long-term predictions.Reinforced learning is frequently used as a part of artificial neural network's overall learning algorithm.

3.4.2 Matlab neural network

Neural Network Toolbox™ provides functions and applications for modeling complex nonlinear systems that are not easily modeled with a closed-form equation. Neural Network Toolbox supports supervised learning with feedforward, radial basis, and dynamic networks. It also supports unsupervised learning with self-organizing maps and competitive layers. Neural Network Toolbox for applications such as data fitting, pattern recognition, clustering, time-series prediction, and dynamic system modeling and control.

3.4.2.1 Algorithm

Levenberg-Marquardt algorithm was designed to approach second-order training speed without having to compute the Hessian matrix. When the performance function has the form of a sum of squares (as is typical in training feedforward networks), then the Hessian matrix can be approximated as

$$H = J^T J \qquad \textbf{(3.1)}$$

and the gradient can be computed as

$$g = J^T e \qquad \textbf{(3.2)}$$

where J is the Jacobian matrix that contains first derivatives of the network errors with respect to the weights and biases, and e is a vector of network errors. The Jacobian matrix can be computed through a standard backpropagation technique that is much less complex than computing the Hessian matrix.

The Levenberg-Marquardt algorithm uses this approximation to the Hessian matrix in the following Newton-like update:

$$x_{k+1}=x_k-[J^TJ+\mu I]^{-1}J^Te \qquad \textbf{(3.3)}$$

When the scalar μ is zero, this is just Newton's method, using the approximate Hessian matrix. When μ is large, this becomes gradient descent with a small step size.

Newton's method is faster and more accurate near an error minimum, so the aim is to shift toward Newton's method as quickly as possible. Thus, μ is decreased after each successful step (reduction in performance function) and is increased only when a tentative step would increase the performance function. In this way, the performance function is always reduced at each iteration of the algorithm.

Training Algorithms

As an illustration of how the training works, consider the simplest optimization algorithm gradient descent. It updates the network weights and biases in the direction in which the performance function decreases most rapidly, the negative of the gradient. One iteration of this algorithm can be written as

$$\mathbf{x}_{k+1}=\mathbf{x}_k-\alpha_k\mathbf{g}_k \qquad \textbf{(3.4)}$$

where xk is a vector of current weights and biases, gk is the current gradient, and αk is the learning rate. This equation is iterated until the network converges.

3.4.2.2 Workflow for neural network design

The work flow for the neural network design process has seven primary steps.

1. Collect data
2. Create the network
3. Configure the network
4. Initialize the weights and biases
5. Train the network
6. Validate the network
7. Use the network

The Neural Network Toolbox software uses the network object to store all of the information that defines a neural network. This topic describes the basic components of a neural network and shows how they are created and stored in the network object.

After a neural network has been created, it needs to be configured and then trained. Configuration involves arranging the network so that it is compatible with the problem you want to solve, as defined by sample data.

After the network has been configured, the adjustable network parameters (called weights and biases) need to be tuned, so that the network performance is optimized. This tuning process is referred to as training the network.

3.4.3 Application of neural network

Neural networks are successfully applied miscellenaous areas.

Medical	Industrial	Finance
Science	Educational	Energy
Sales&Marketing	Operational Analysis	

3.4.4 Benefits of neural network

Using of neural networks offer variety benefits;

- ✓ Neural networks are a useful technique to solvevariousreal world problems.
- ✓ They are able to deal with incomplete information and unstabledata in order to evaluate the problem.
- ✓ Neural Networks can be very effective in some conditions where it is impossible to define the rules or steps that obtain to the solution of a problem.
- ✓ They resist to errors in the training data.

- ✓ In order to improve their performance, they have the ability to learn from experience so that they can adapt themselves to variations in the environment.

4. SPAR TYPE FLOATING WIND TURBINE ANALYSIS

The aim of this thesis is performing the simulation of floating wind turbines. Thesimulationsareperformed indifferent environmental conditionswhich are affected by the wind speed, wave height, water depth and current velocity variables. Simulation cases are groupedaccording to number of mooring lines so there are three different cases in the simulation studies. The application are of the study is decided to be Aegean Sea.

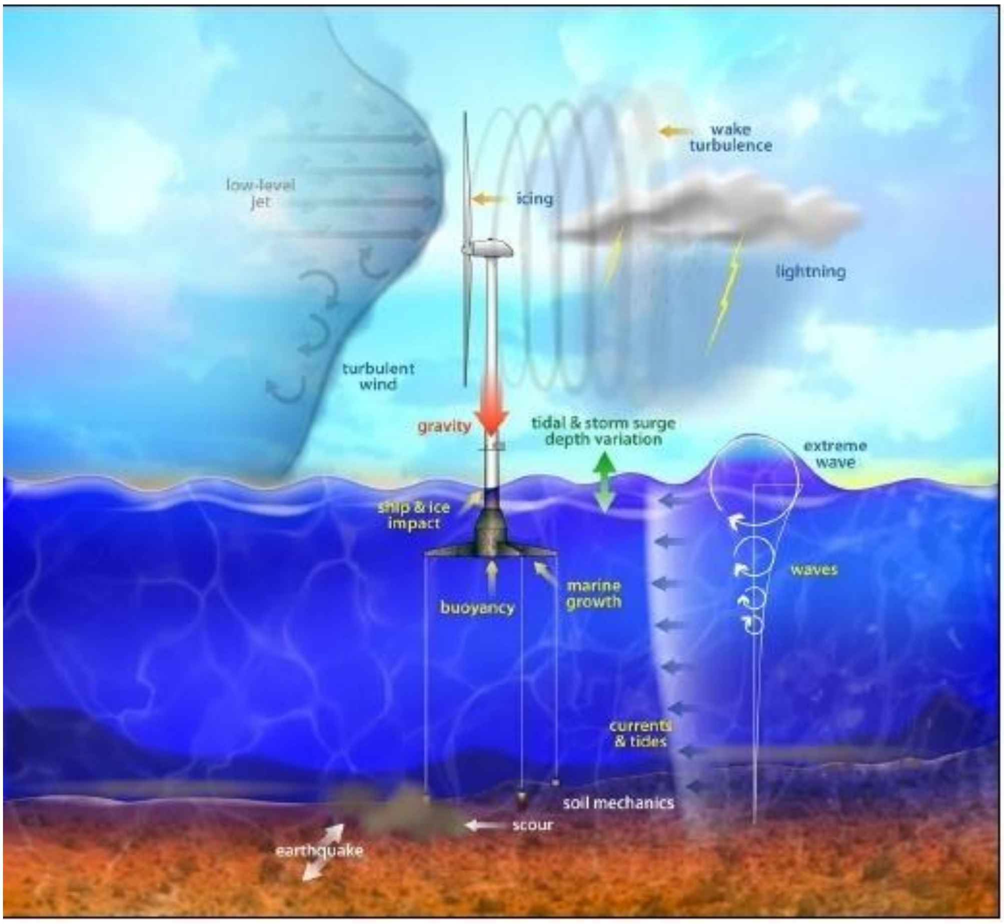

Figure 4.1 : Loads on an offshore wind turbine (Jonkman 2007).

In this study, specific wind turbine which is known NREL offshore 5MW monopile wind turbine was used. This turbine has 3 blades with with variable speed.

In the currentstudy, specific wind turbine, which is known NREL offshore 5MW monopile wind turbine, was used. This turbine has three blades with variable speed options andcollective pitch control. In the following table the main properties of NREL wind turbine are presented.

Table 4.1 : NREL 5-MW baseline wind turbine. (Jonkman, 2009).

Property	Specification
Rated power	5 MW
Rotor orientation	Upwind
Rotor configuration	3 blades, 61.5-m length
Rotor, hub diameter	126 m, 3 m
Hub height	90 m
Cut-in (Vın)	3m/s
Rated	11,4m/s
Cut-out (Vout)	22-23-24 m/s
Cut-in rotor speed	6.9 rpm,
Rated rotor speed	12.1 rpm
Drivetrain concept	Geared
Gearbox ratio	97:1
Rated generator speed	1173.7 rpm
Generator efficiency	94.4 %
Rated tip-speed	80 m/s
Overhang	5m
Shaft tilt	5°
Precone	2.5°
Rotor mass	110,000/kg
Nacelle mass	240,000/kg
Tower mass	347,460/kg
Tower diameter base,	6m
Tower top diameter	3,87m
CM location	-0.2 m, 0.0 m, 64.0 m
Control system	Variable-speed generator torque & collective active pitch (PI)

Mooring System

An integral part of all floating platform concepts is the mooring system.Thereforemooring systems are most important component in the SPAR design. Mooring systems consist of cables attached to thefloating platform at fairlead connections with the lower ends anchored to the seabed. There arevarious types of cables availablesuchas chains, steel, synthetic fibers, or a combination ofthese.

This study is performed with the OC3-HyWind platform in regular waves. In the following table the OC3-HyWind platform properties are presented.

Table 4.2 : Properties of OC3-Hywind System(Jonkman,2007).

Static Properties	Value
Total draft	120 m
Elevation to platform top	10 m
Depth to top of taper below SWL	4 m
Depth to bottom of taper below SWL	12 m
Platform diameter above taper	6.5 m
Platform diameter below taper	9.4 m
Platform mass	7,466,330 kg
Center of mass location below SWL	89.9155 m
Water depth	350 m
Total displacement	8,029.21 m^3
Unstreched mooring-line length	902.2 m
Radius to anchors from centerline	853.87 m
Line diameter	0.09 m
Line extensional stiffness	384,243,000 N
Line mass per unit length	77.7066 kg

OC3-HyWind platform model is showed in Figure 9.

Figure 4.2 : OC3-HyWind platform (Jonkman,2007).

For each case; simulation parameters are presented below.

Environmental Properties:

- Area: Aegean Sea
- Water Depth: 350m
- Wave height:
  - ✓ 4m Tp = 7.8s
  - ✓ 5m 4m Tp = 8s
  - ✓ 6m Tp =8.2s
  - ✓ 7m Tp = 8.4s
- Current velocity :
  - ✓ 2 knot
  - ✓ 3 knot
- Wind velocity:
  - ✓ 15 knot
  - ✓ 30 knot
  - ✓ 45 knot
  - ✓ 60 knot

Analysis

- Total run time: 1200 seconds
- Integration time step: 0.01

Case 1 : Three PointMooring Lines

Step 1: Modelling

Before the analysis,spar type wind turbine is modelled at the Orcaflex data file where it is linked to Fastlink program. Wave height, wave peak period and current velocity variables are inputs to the data folder. However, data of wind velocity are stayed in "wnd." file.

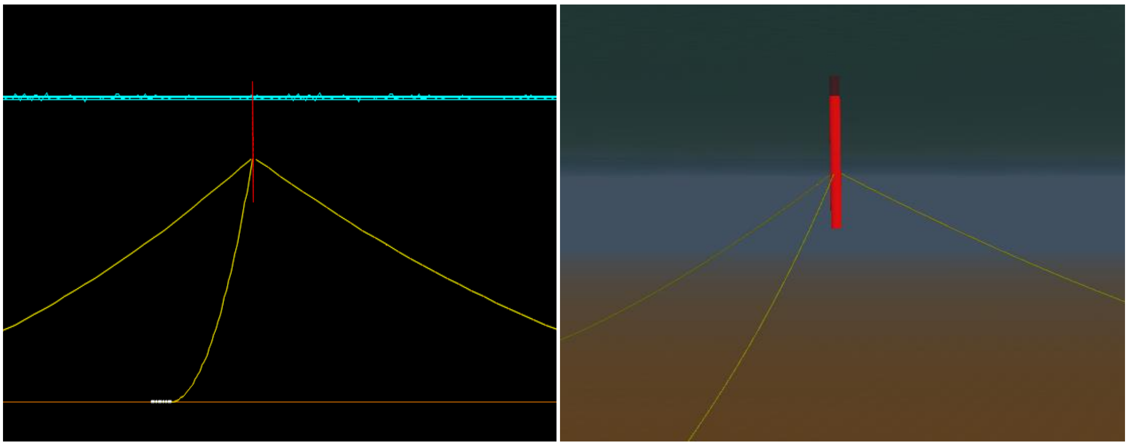

Figure 4.3 : OC3-HyWind platform (3point mooring lines).

Step 2: Analysis

All parameters are provided in the data folders and then simulation is initiated by the the coupled FAST and OrcaFlex Batch file. Fastlink computes aerodynmacis and hydrodynamics results. Hydrodynamic results are obtained from Orcaflex simulation file. The results include displacement and rotations at the global coordinate system. The resultsare shown in table 5.3 for three point mooring lines.

Table 4.3 : Result of displacements and rotation.

Sim. No	x	y	z	rot1	rot2	rot3
1	7,6798	0,017	2,3456	0,0138	1,0373	0,066
2	10,7386	0,0602	2,3974	0,0521	1,8834	0,2691
3	15,8358	0,19	2,5068	0,1816	3,6619	0,7631
4	22,842	0,9428	2,8495	0,9979	5,9715	5,6090
5	13,7906	0,0149	2,3602	0,0124	1,1624	0,0584
6	16,2826	0,0526	2,4224	0,0491	1,9846	0,2244
7	20,295	0,161	2,699	0,168	3,697	0,642
8	26,297	0,773	3,208	0,974	5,924	5,439
9	7,880	0,018	2,357	0,015	1,286	0,079
10	10,999	0,064	2,405	0,054	1,933	0,277
11	16,0103	0,2024	2,5039	0,191	3,6811	0,814
12	22,8998	0,9419	2,8138	1,0102	5,9221	5,7528
13	13,9897	0,0159	2,3731	0,0134	1,4369	0,0654
14	16,4415	0,0567	2,4312	0,0515	2,0373	0,2528
15	20,5027	0,1681	2,6967	0,1753	3,7115	0,6827
16	26,3846	0,7781	3,1904	0,9885	5,8818	5,5982
17	8,1599	0,0214	2,3672	0,0179	1,5905	0,0891
18	11,2316	0,0674	2,4107	0,0602	2,168	0,2901
19	16,1282	0,2148	2,4962	0,2012	3,6757	0,8624
20	22,767	0,9162	2,8761	1,0132	5,8536	5,8978
21	14,2601	0,0183	2,3853	0,0163	1,7597	0,0726
22	16,6552	0,0611	2,4389	0,0567	2,3084	0,2592
23	20,6714	0,1769	2,6781	0,1849	3,7099	0,7105
24	26,3554	0,772	3,2498	0,999	5,8253	5,7887
25	8,95	0,0282	2,3765	0,024	2,0084	0,1005
26	11,549	0,0869	2,4151	0,0786	2,5038	0,3104
27	16,3215	0,2241	2,4863	0,2126	3,6498	0,91
28	22,7133	0,8866	2,9442	1,0174	5,7661	6,0929
29	14,8224	0,0231	2,3966	0,0205	2,1738	0,0936
30	16,9971	0,0798	2,4457	0,0727	2,6306	0,2763
31	20,8502	0,1871	2,7467	0,1965	3,7004	0,747
32	26,246	0,8128	3,3073	1,0085	5,7506	6,0112

Table 4.3 shows that displacement of x direction is highly affected by the variations in the wind velocity and wave height. Differences in the amount of displacement at the z direction are in small order due to the stiffness of the mooring lines.

Figure 4.4 shows that displacements of x direction at the max conditions (wave height, current velocity and wind velocity) for three point mooring lines.

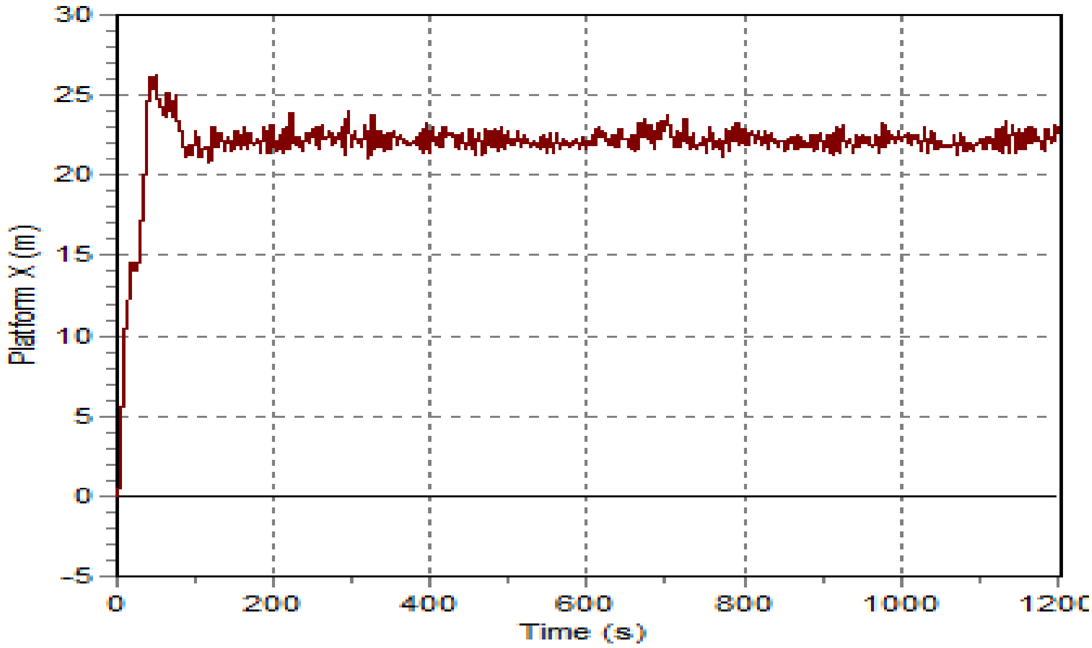

Figure 4.4 : Displacement of x-direction.

Step 3: Neural Network

Neural network fitting tool in MATLAB is used for modelling of the problem in this wind turbine. Mainly, two matricesare created for the analysis. All input data are recognized by the neural network and then all results are defined for target data to obtain network output.

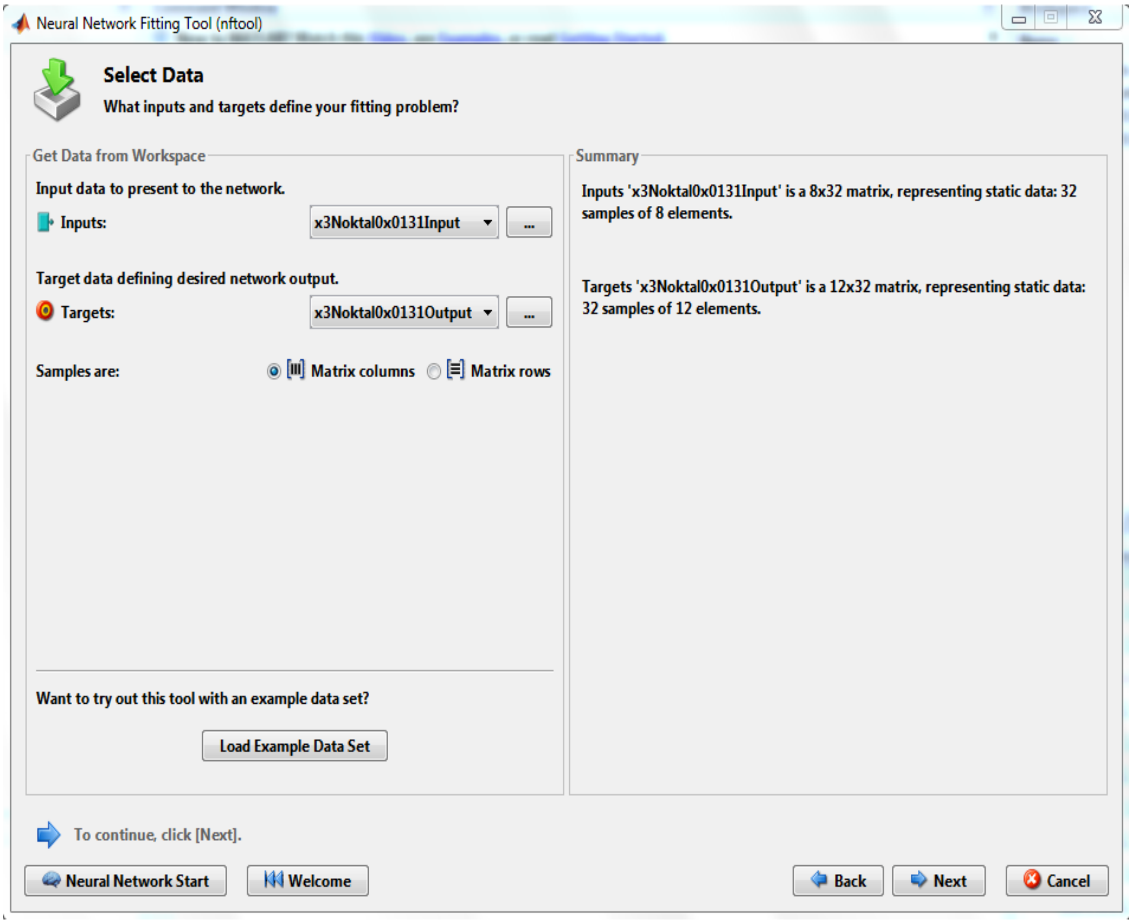

Figure 4.5 : Neural Network Fitting.

Training phase is initiated with the fitting process of the inputs and targets. When the training phase is completed, regression result can be obtained (Figure 5.4).

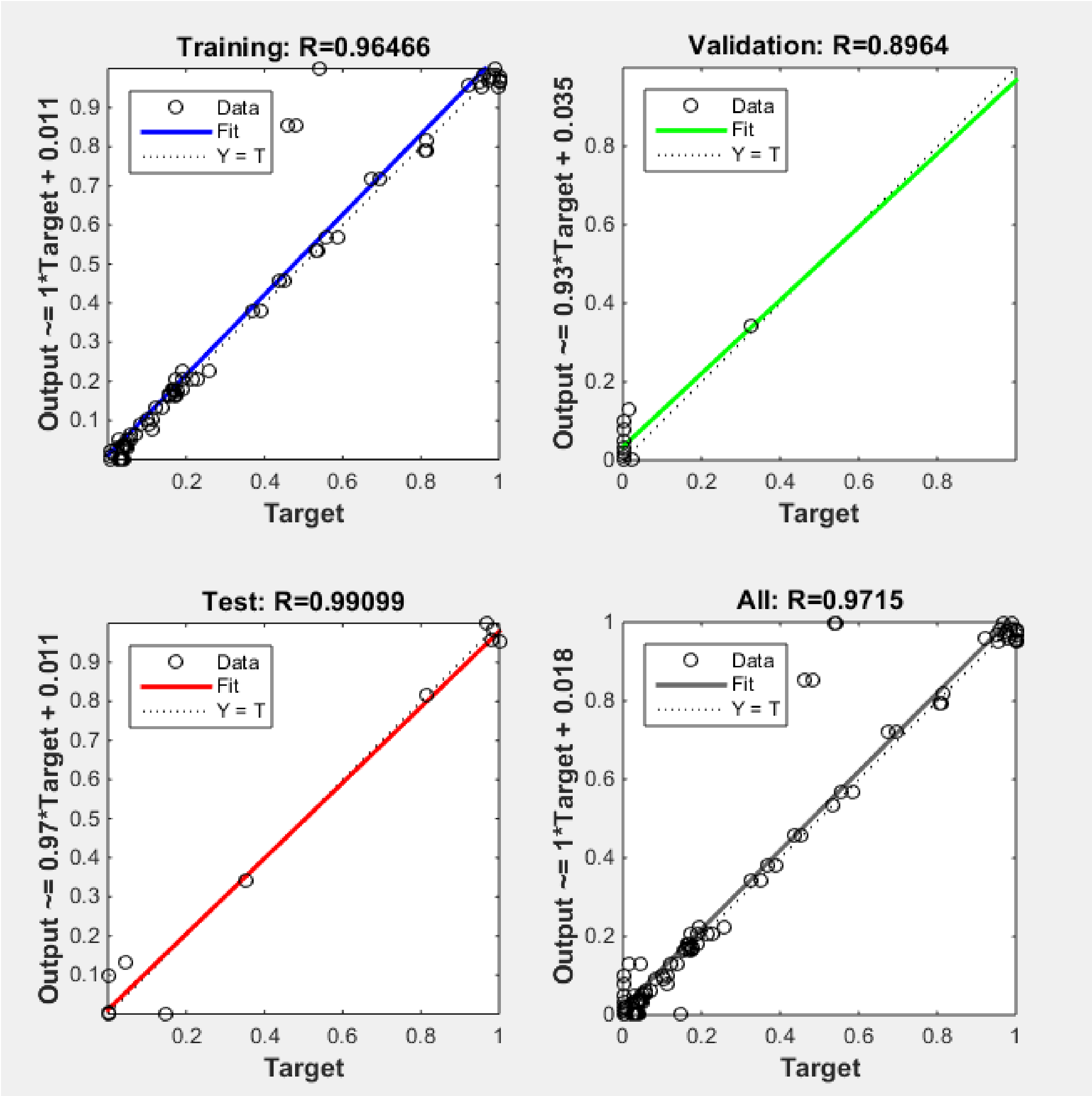

Figure 4.6 : Neural Network Training Regression.

Figure 4.5 consists of four graphics. Training phase uses %70 of data and training graphics shows that training of neural network has a success percentage of %88 compared to FASTlink result. Validation test phases use %30 of the global dataprovided. Therefore, the neural network model is adapted the data and the targetwith a success rate of %90.

Figure 4.6, 4.7 and 4.8 show comparisons of ANN and FASTlink analysis results for x,y,z direction. It is clearly observed that there are small differences between two models.

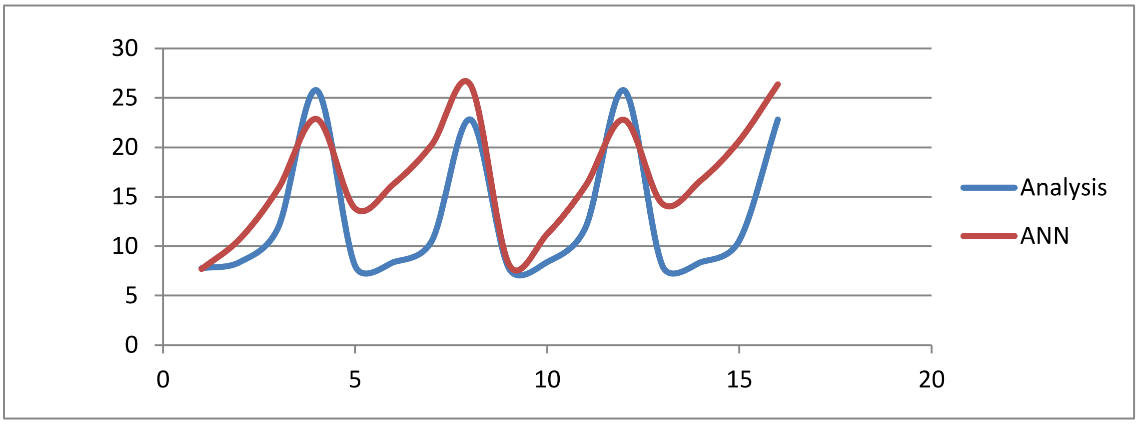

Figure 4.7 : Comparasion of ANN and Analysis Result (x-direction).

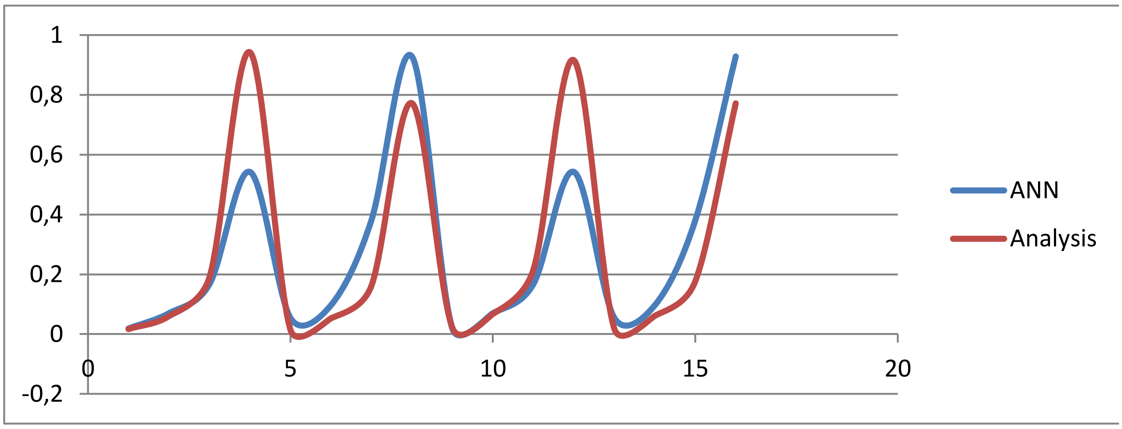

Figure 4.8 : Comparasion of ANN and Analysis Result (y-direction).

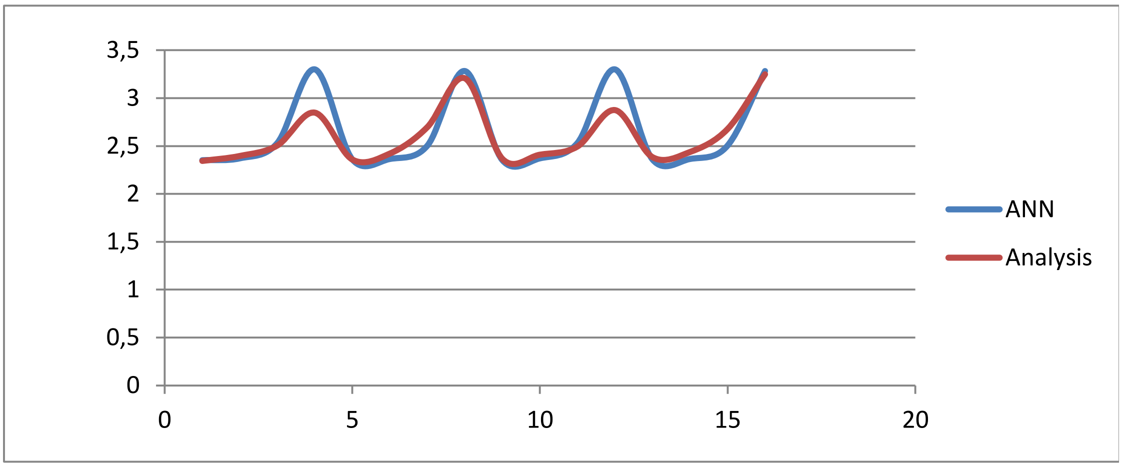

Figure 4.9 : Comparasion of ANN and Analysis Result (z-direction).

Case 2 : Four Point Mooring Lines

Spar wind turbine is modelled with four point mooring lines. All steps apply for this case. Figure 4.8 shows two and three dimesion model of wind turbine.

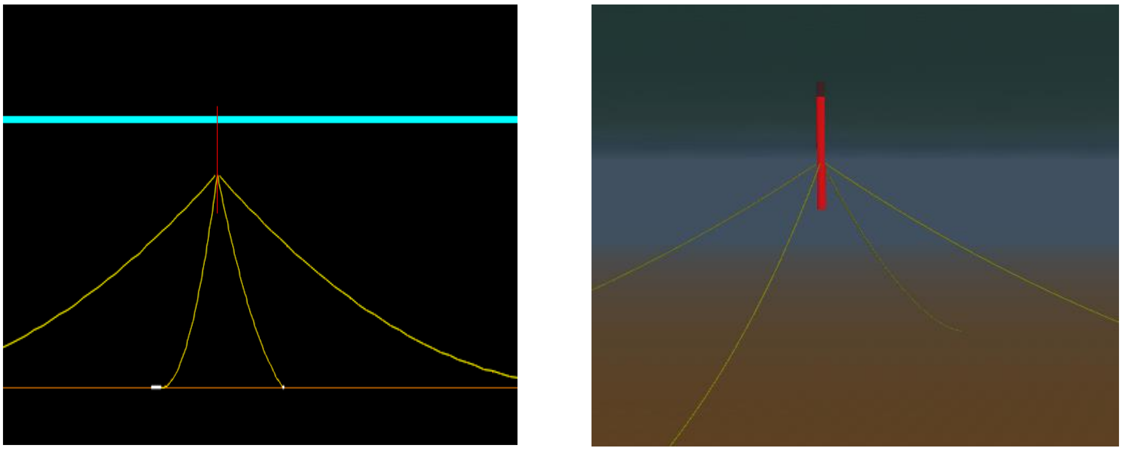

Figure 4.10 : OC3-HyWind platform (4 point mooring lines).

Table 4.4 shows all similation results for four point mooring lines.

Table 4.4 : Result of displacements and rotation.

Sim. No	x	y	z	rot1	rot2	rot3
1	6,065	-0,016	-5,604	0,014	0,990	-0,089
2	8,387	-0,058	-5,647	0,053	1,787	0,249
3	12,006	-0,160	-5,742	0,161	3,479	0,596
4	16,429	-0,844	-5,913	1,037	5,690	4,023
5	10,024	-0,014	-5,422	0,012	1,143	-0,077
6	11,904	-0,050	-5,473	0,049	1,897	0,205
7	14,815	-0,133	-5,581	0,148	3,525	0,463
8	18,576	-0,684	-5,773	0,950	5,655	3,968
9	6,416	-0,017	-5,596	0,015	1,271	-0,093
10	8,658	-0,059	-5,637	0,054	1,854	0,246
11	12,252	-0,166	-5,725	0,167	3,475	0,600
12	16,696	-0,864	-5,880	1,061	5,624	4,152
13	10,294	-0,015	-5,419	0,013	1,410	0,080
14	12,158	-0,052	-5,467	0,051	1,994	0,208
15	15,114	-0,141	-5,567	0,155	3,522	0,506
16	18,795	-0,708	-5,741	0,976	5,591	4,074
17	6,738	-0,020	-5,580	0,017	1,616	-0,102
18	9,000	-0,064	-5,619	0,058	2,151	0,263
19	12,576	-0,173	-5,700	0,176	3,452	0,628
20	16,931	-0,903	-5,837	1,085	5,534	4,332
21	10,578	-0,017	-5,408	0,014	1,730	0,096
22	12,434	-0,056	-5,455	0,054	2,293	0,211
23	15,368	-0,146	-5,546	0,159	3,505	0,521
24	18,985	-0,748	-5,701	1,003	5,501	4,177
25	7,276	-0,025	-5,556	0,022	2,012	-0,106
26	9,280	-0,078	-5,592	0,069	2,499	0,267
27	12,822	-0,181	-5,665	0,183	3,575	0,636
28	17,088	-0,956	-5,789	1,118	5,637	4,538
29	10,925	-0,020	-5,390	0,018	2,092	0,101
30	12,655	-0,060	-5,435	0,055	2,614	0,205
31	15,556	-0,153	-5,518	0,166	3,646	0,565
32	19,107	-0,783	-5,657	1,033	5,645	4,276

Same environmental conditions for case two, neural network results shown in Figure 4.11

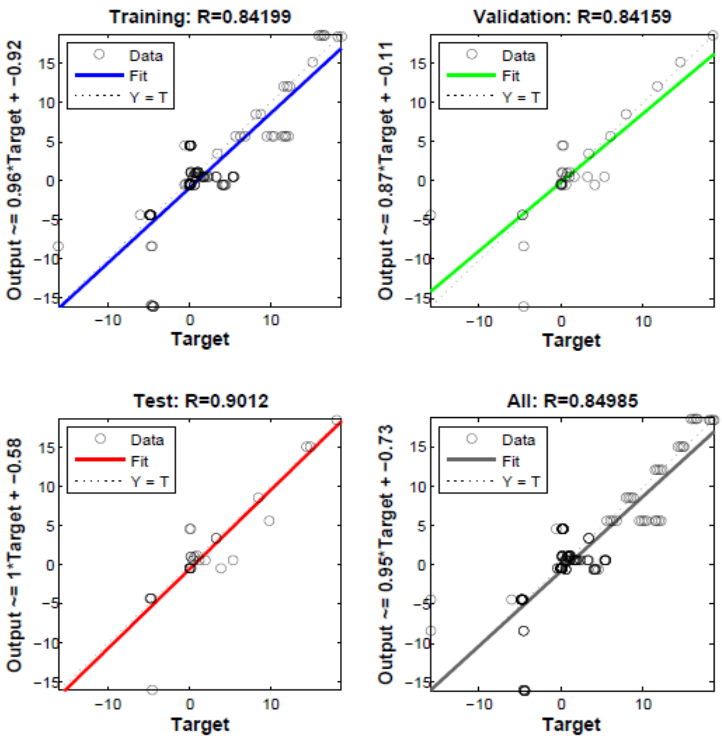

Figure 4.11 : Neural Network Training Regression.

Case 3 : Six Point Mooring Lines

Spar wind turbine is modelled with six point mooring lines. All steps apply for this case. Figure 4.10 shows two and three dimension model of wind turbine.

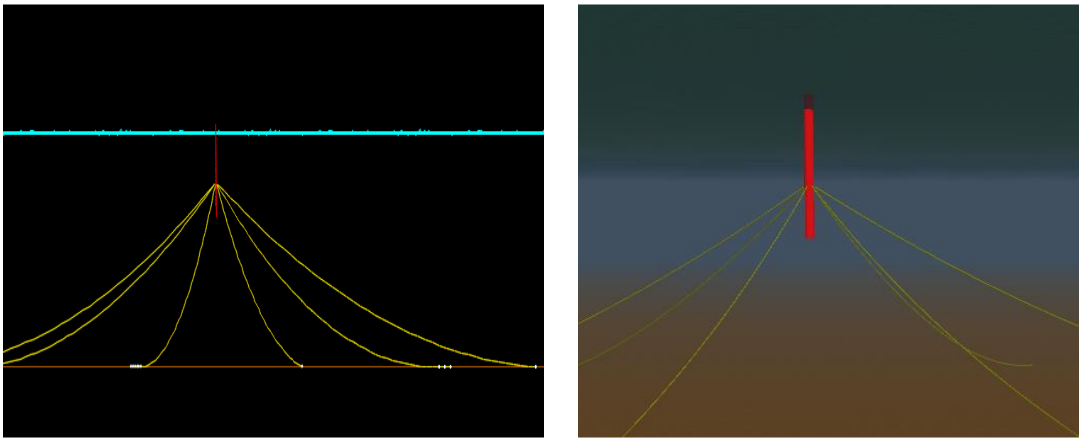

Figure 4.12 : OC3-HyWind platform (6 point mooring lines).

Table 4.4 shows all similation results for four point mooring lines.

Table 4.5 : Result of displacements and rotation.

Sim. No	x	y	z	rot1	rot2	rot3
1	4,587	-0,015	-11,304	0,013	0,951	0,110
2	6,562	-0,052	-11,335	0,051	1,621	0,220
3	9,783	-0,128	-11,405	0,151	3,182	0,505
4	14,002	-0,559	-11,533	0,613	5,255	2,478
5	7,983	-0,013	-10,992	0,011	1,111	0,100
6	9,717	-0,046	-11,029	0,052	1,742	0,234
7	12,526	-0,123	-11,107	0,149	3,244	0,499
8	16,195	-0,477	-11,242	0,581	5,237	2,454
9	3,941	-0,016	-11,278	0,013	0,319	0,039
10	6,836	-0,054	-11,307	0,053	1,775	0,240
11	8,152	-0,130	-9,253	0,155	3,156	0,537
12	14,174	-0,560	-11,484	0,622	5,183	2,539
13	7,385	-0,013	-7,697	0,012	1,378	0,105
14	9,966	-0,047	-11,001	0,053	1,922	0,247
15	11,703	-0,125	-11,070	0,154	3,218	0,527
16	16,343	-0,484	-11,195	0,596	5,166	2,514
17	5,560	-0,017	-11,240	0,014	1,565	0,118
18	5,520	-0,053	-6,776	0,055	2,079	0,265
19	10,240	-0,133	-11,325	0,161	3,251	0,582
20	14,227	-0,558	-11,424	0,621	5,246	2,607
21	8,847	-0,014	-10,929	0,012	1,697	0,106
22	10,180	-0,048	-10,961	0,055	2,210	0,262
23	12,931	-0,127	-11,029	0,158	3,315	0,567
24	16,386	-0,484	-11,138	0,612	5,255	2,577
25	6,160	-0,020	-11,191	0,017	1,920	0,130
26	7,477	-0,058	-11,215	0,057	2,393	0,284
27	10,371	-0,139	-11,267	0,165	3,498	0,613
28	14,158	-0,555	-11,357	0,636	5,485	2,668
29	9,449	-0,017	-10,881	0,014	2,056	0,125
30	10,671	-0,050	-10,912	0,056	2,523	0,282
31	13,057	-0,129	-10,974	0,162	3,561	0,603
32	16,329	-0,475	-11,076	0,629	5,493	2,630

Same environmental conditions for case three, neural network results shown in Figure 4.10

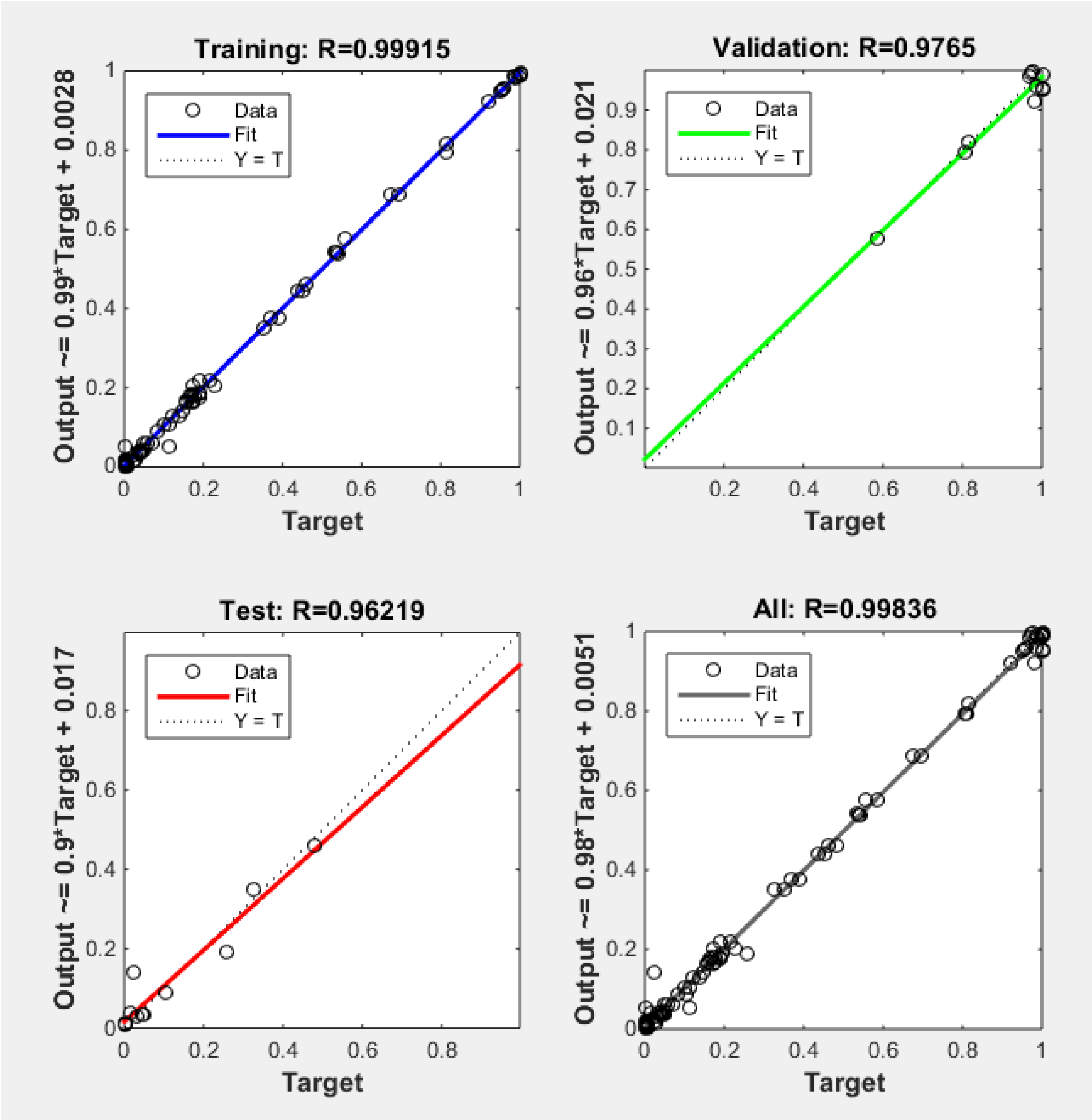

Figure 4.13 : OC3-HyWind platform (6 point mooring lines).

5. CONCLUSIONS AND RECOMMENDATIONS

In this study, a SPAR type floating wind turbine was modeled under extreme weather conditions by using OrcaFlex and Fast programs. Using these programs, the response of the offshore structure was investigated. To forecast the response of the SPAR type floating wind turbine, the data obtained by Orcaflex was used as inputs in Matlab Neural Network Tool. A neural network presents a sophisticated modelling technique that is capable of modelling very complex non-linear functions. An advantage of modelling using neural networks is that they easily overcome the problem of modelling non-linear functions that shall predict a set of output variables dependent on several input variables. In this study, the data successfully applied to neural networks.

The Neural Networkapplication has been very versatile and flexible in applications. Therefore, it can be used and applied in other types of wind turbines.

As future studies, systematic investigation for different platform types of wind turbines can be carried out to see effects of platform shapes.

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APPENDICES

APPENDIX A: Three Point Mooring Lines

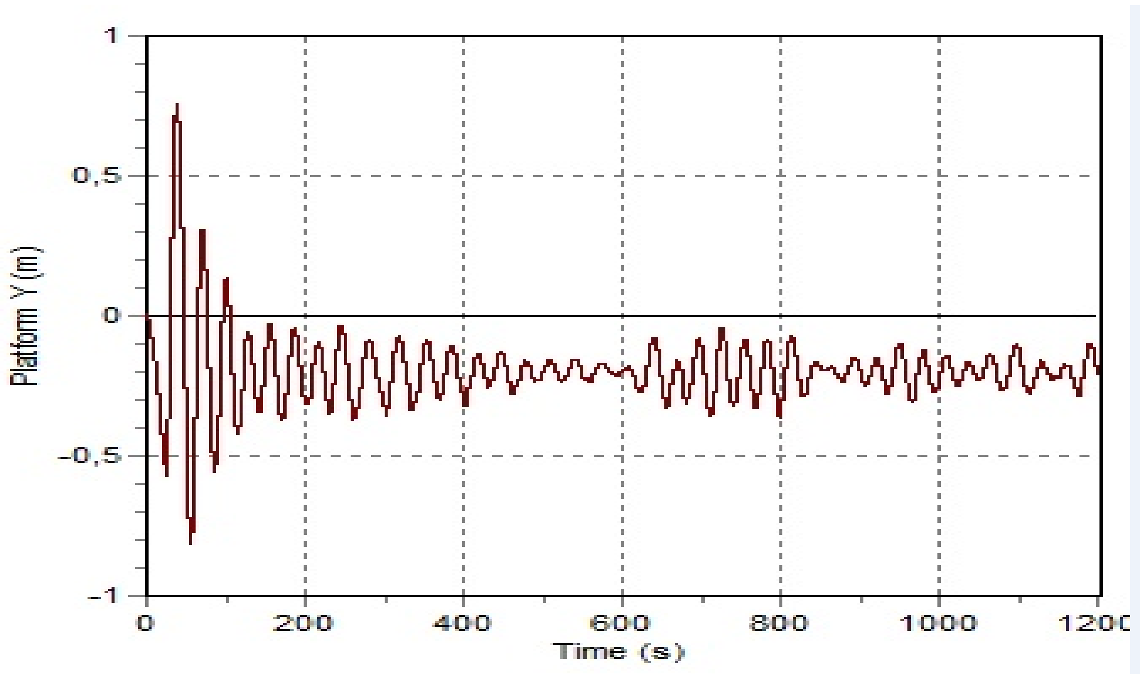

Figure A. 1 : Displacement of y-direction.

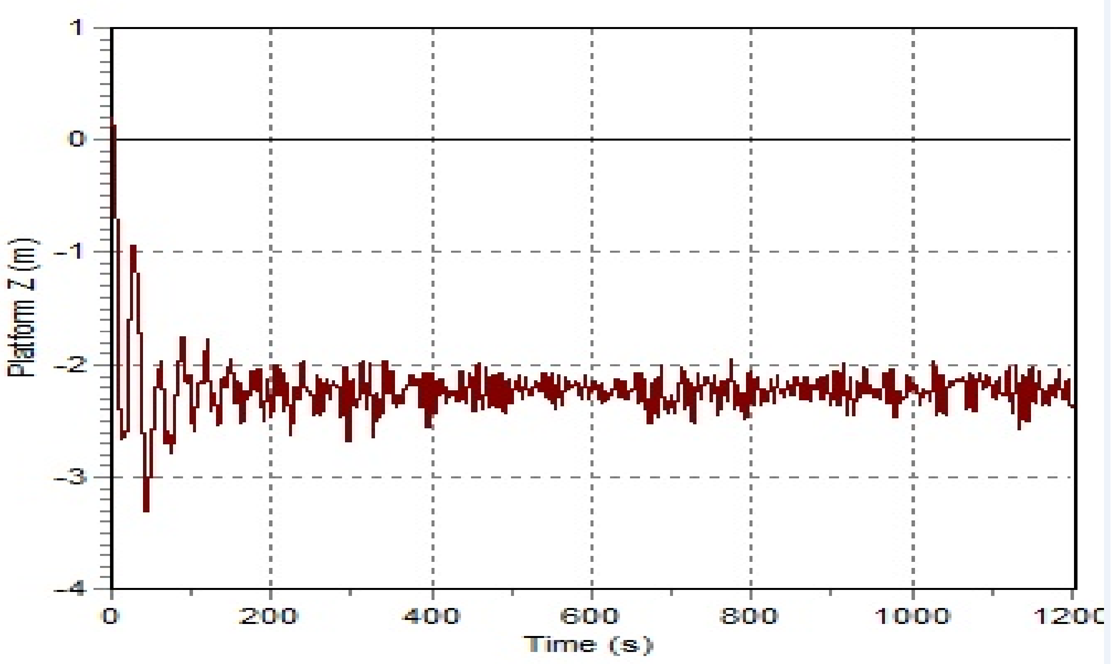

Figure A. 2 : Displacement of z-direction.

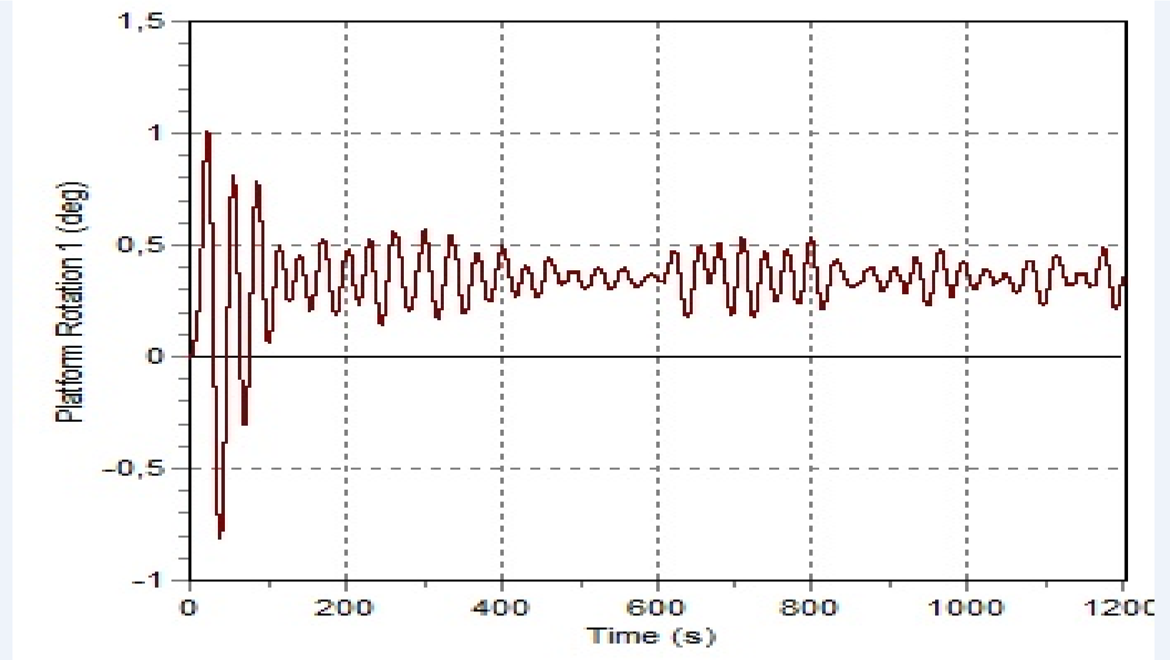

Figure A. 3 : Rotation of x-direction.

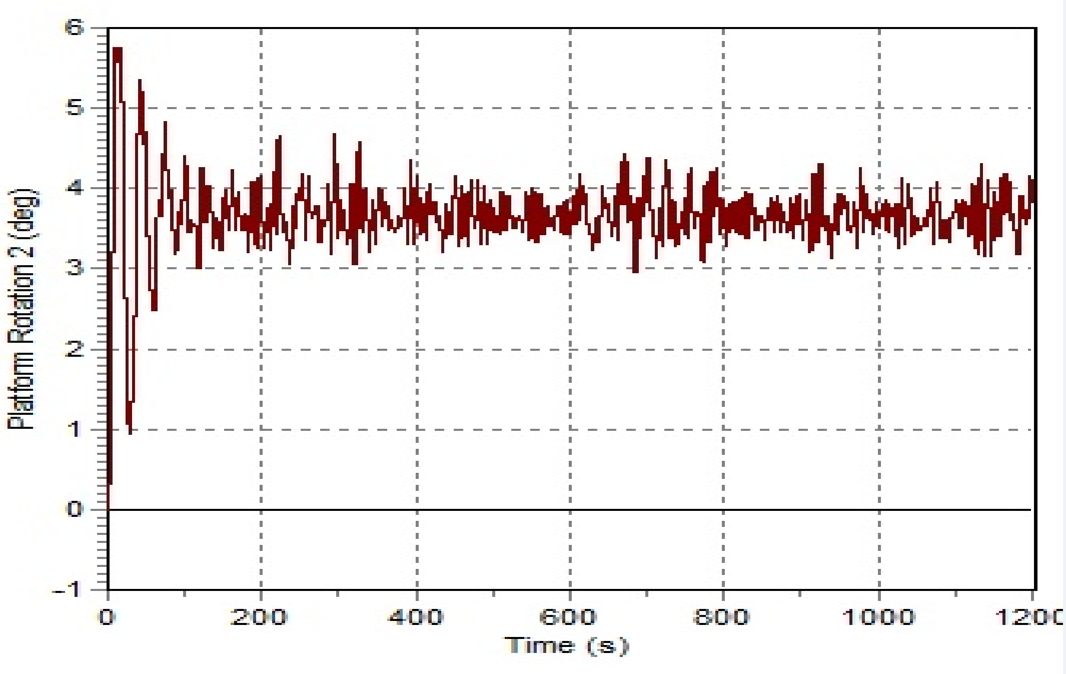

Figure A. 4 : Rotation of y-direction.

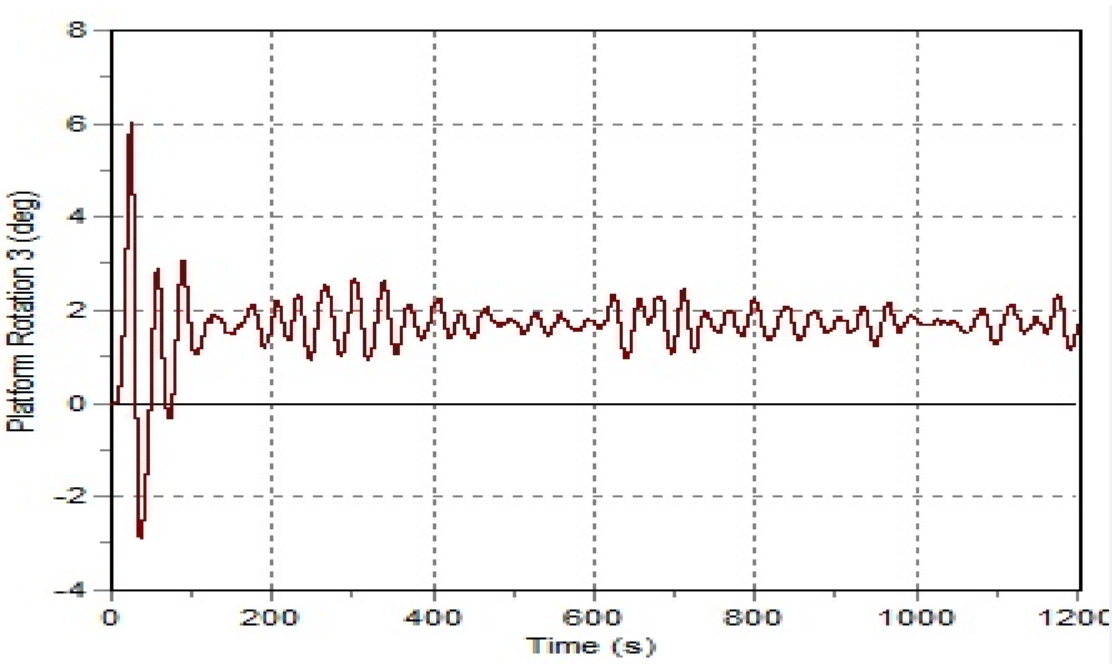

Figure A. 5 : Rotation of z-direction

APPENDIX B: Four Point Mooring Lines

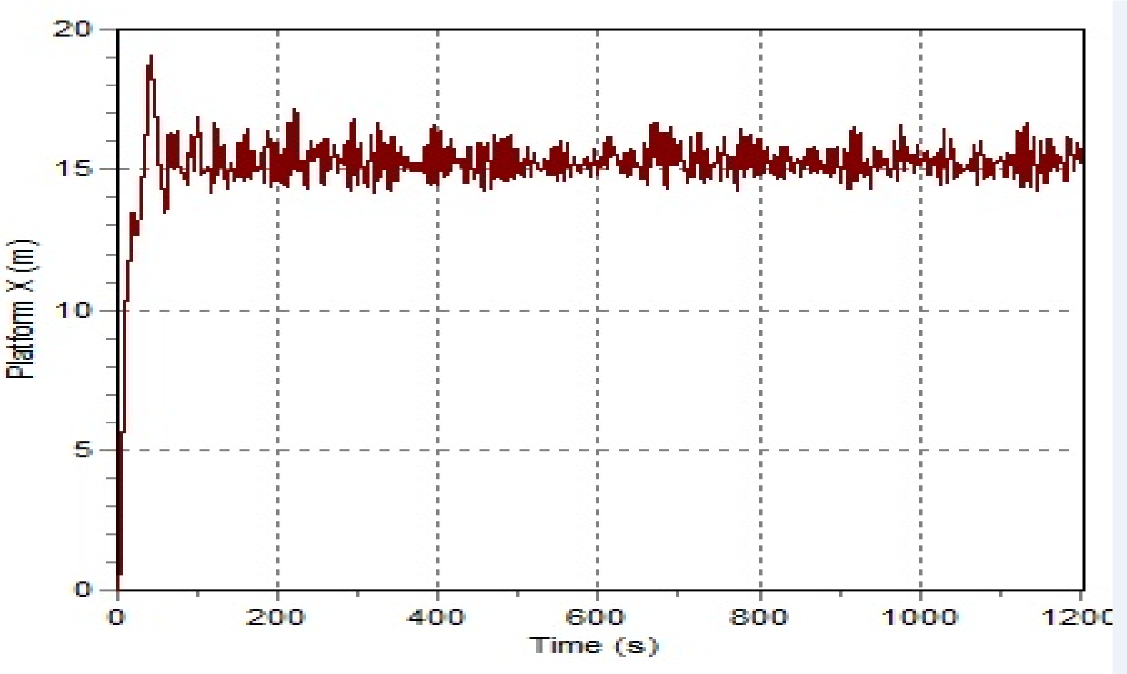

Figure B. 1 : Displacment of x- direction.

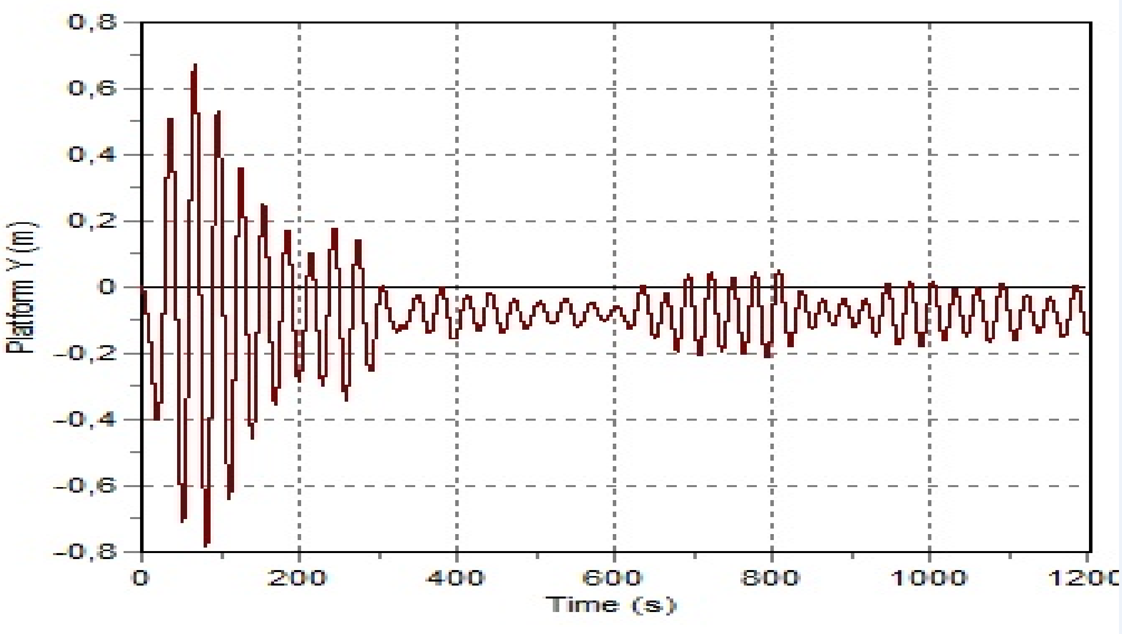

Figure B. 2 : Displacment of y –direction.

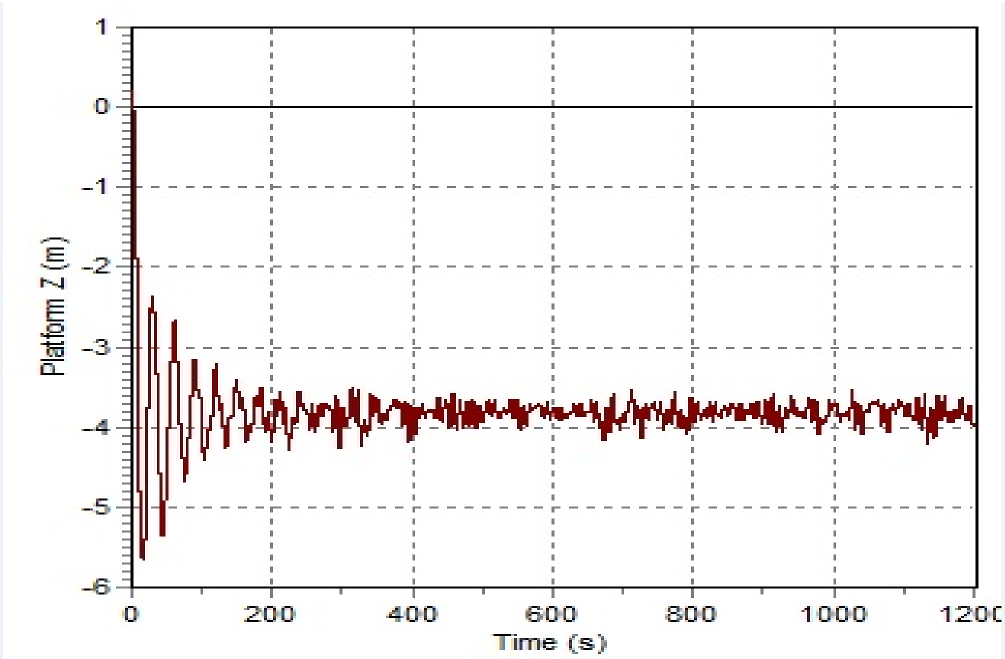

Figure B. 3 : Displacment of z –direction.

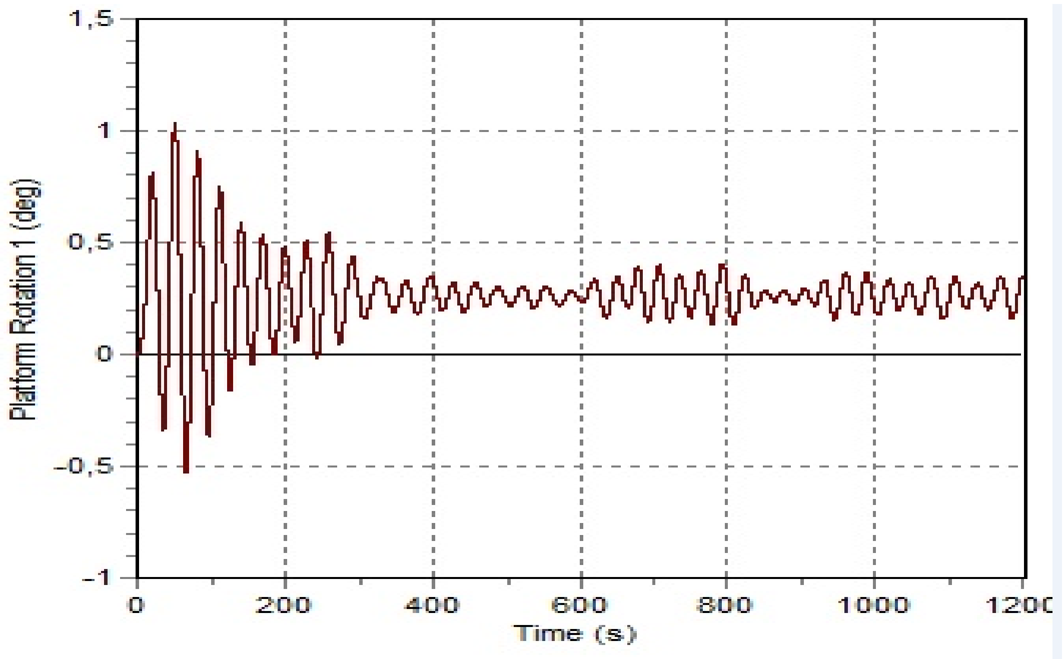

Figure B. 4 : Rotation of x-direction.

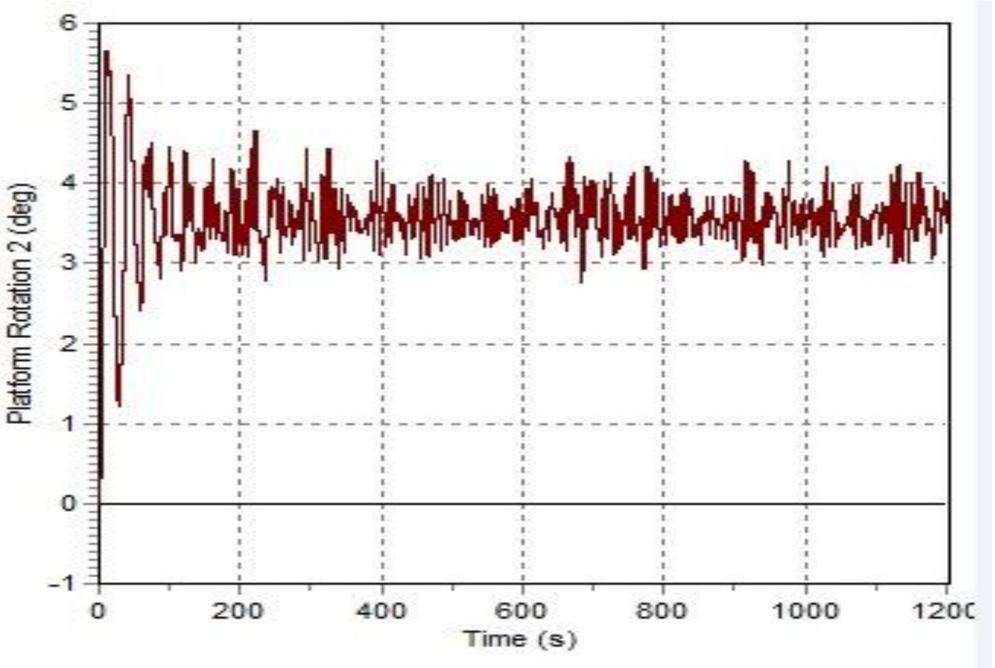

Figure B. 5 : Rotation of y-direction.

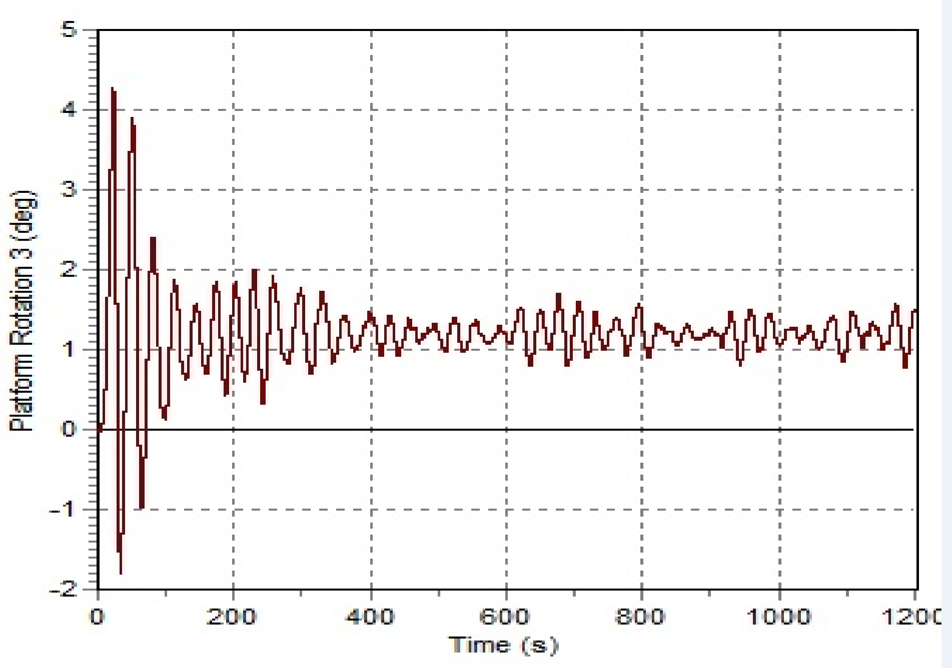

Figure B. 6 : Rotation of z-direction.

APPENDIX C: Six Point Mooring Lines

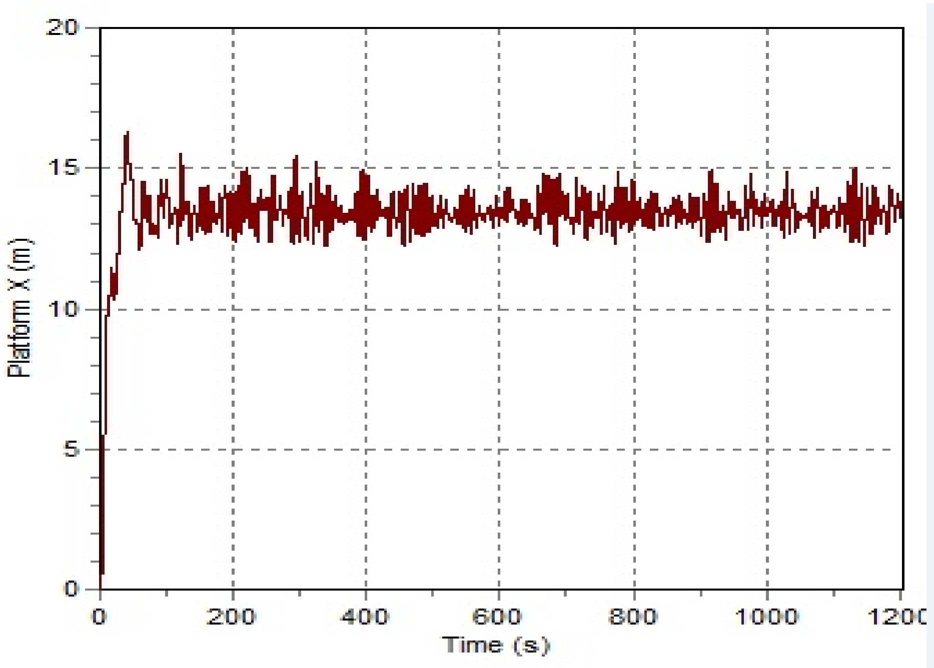

Figure C. 1 : Displacment of x –direction.

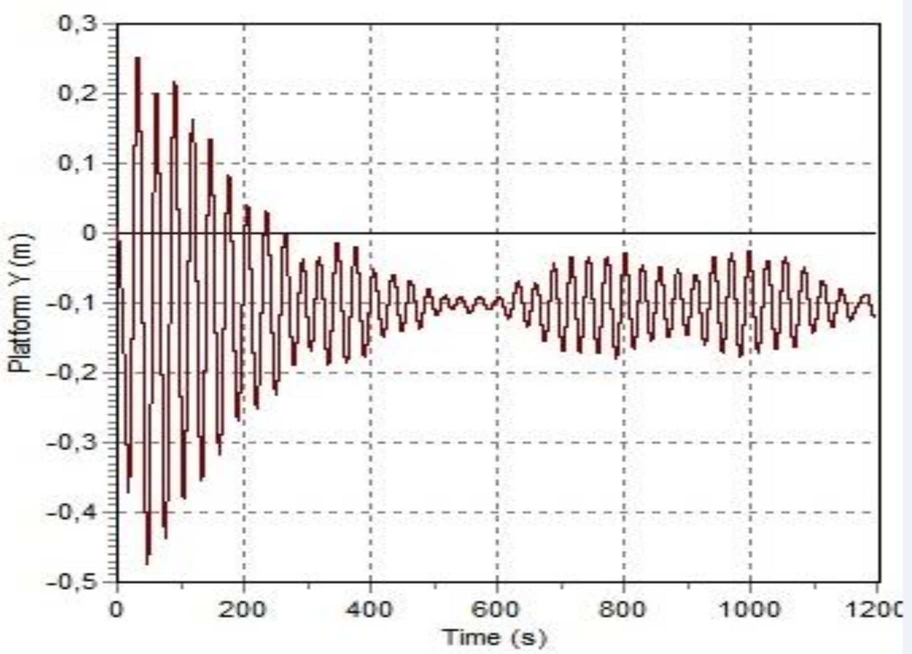

Figure C. 2 : Displacment of y –direction.

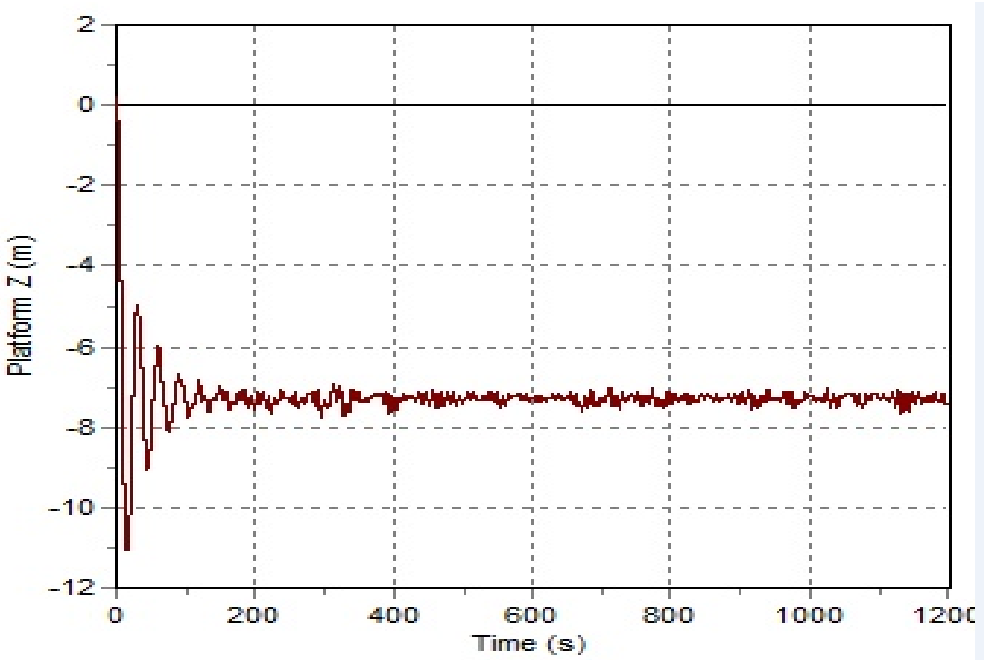

Figure C. 3 : Displacment of z –direction.

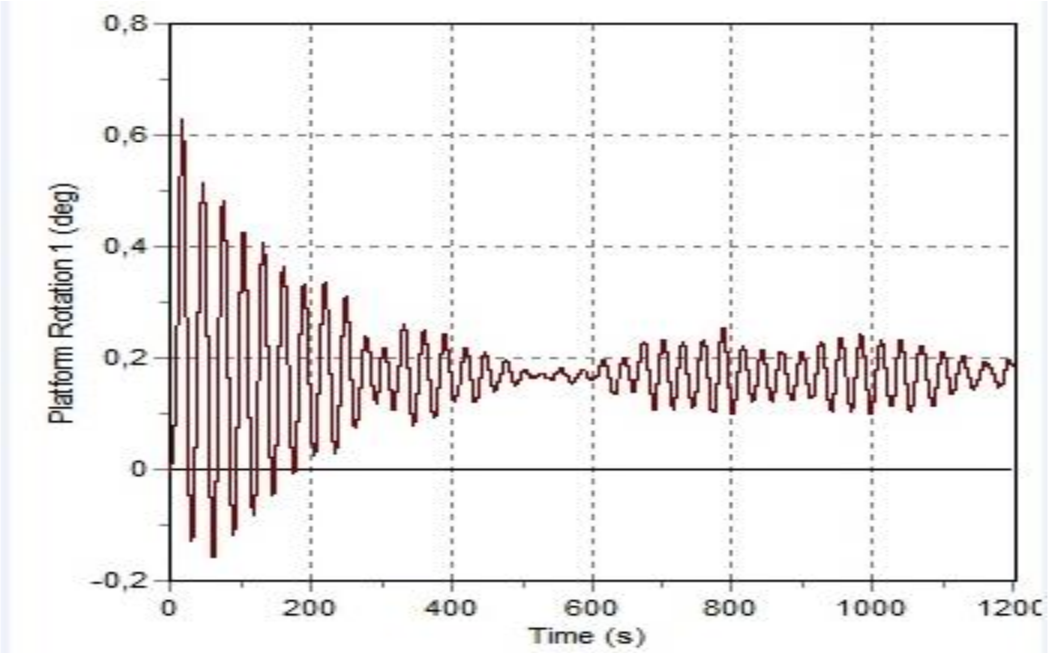

Figure C. 4 : Rotation of x-direction.

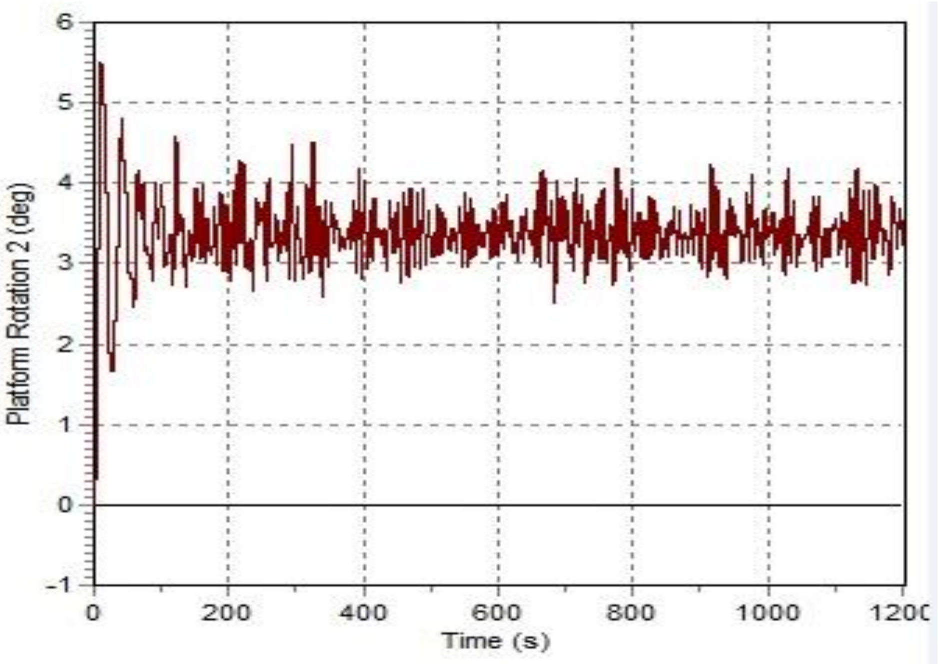

Figure C. 5 : Rotation of y-direction.

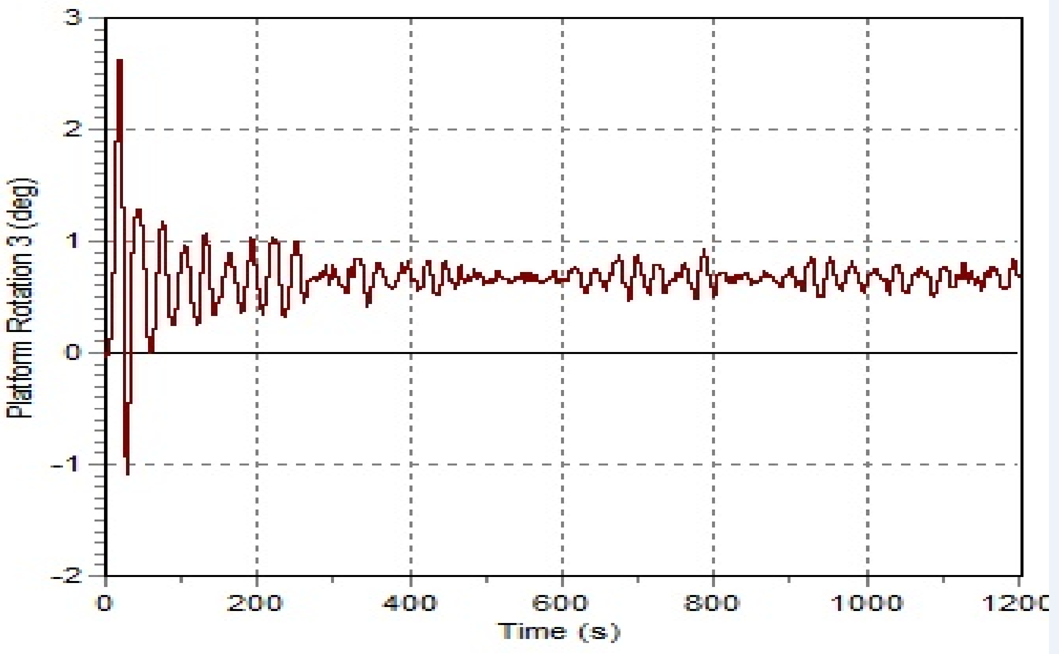

Figure C. 6 : Rotation of z-direction.

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