İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

PRACTICAL DATA ANALYSIS FOR POWER PLANT CONDITION MONITORING

M.Sc. Thesis by
Mustafa KAPLAN

Department : **Mechatronics Engineering**

Programme : **Mechatronics Engineering**

JANUARY 2009

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JANUARY 2009

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

ELEKTRİK SANTRALİ DURUM İZLEME İÇİN PRATİK VERİ ANALİZİ

YÜKSEK LİSANS TEZİ

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FOREWORD

I would like to express my deep appreciation and thanks for my advisor Prof. Dr. Serhat Şeker, both for his guidance and motivation, my friend Emre Onur Parıltay and all other engineers and operators at the EUAS Ambarlı Fuel-Oil Power Plant for their help and support.

December 2008 Mustafa KAPLAN

Mechanical Engineer

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ABBREVATIONS

APH : Air Preheater
BTU : British Thermal Unit
CPSD : Cross Power Spectral Density
DM : Demineraliing Treatment Plant
DWT : Discrete Wavelet Transform
FD : Forced Draft
ID : Induced Draft
kV : Kilo Volts
kVA : Kilo VoltAmperes
mA : Mili Ampere
MRA : Multi-Resolution Analysis
MRWT : Multi-Resolution Wavelet Transform
MW : Mega Watts
mV : Mili Volt
RPM : Revolution per Minute
STFT : Short-time Fourier Transform

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PRACTICAL DATA PROCESSING AND ANALYSING FOR POWER PLANT TURBINE CONDITION MONITORING

SUMMARY

As maintenance develops, newer techniques appear. One of the important subjects on maintenance is condition monitoring. With the help of condition monitoring, predictive maintenance techniques can be applied to machinery, which is both efficient and economic. While talking about efficiency and economy, it is necessary to remind that power plants are one of the big-scale industrial developments and has generally not only economic but also strategic role. This makes power plants a prior environment for highly efficient maintenance techniques to be used. Furthermore, power plants has a lot of components ranging from pure mechanical parts to complex electro-mechanical ones. The most critical component of a power plant is turbine&generator complex, and it must always be in good condition both because of the safety and plant efficiency issues.

To have a practice on power plants, mechatronical parts, data conditioning and analysis; this work includes plant investigations, a development of a data acquisition system, data conversion, software, data conditioning and data analysis.

A brief instruction about thermal power plants and components was followed by a condition monitoring system for an active plant: EUAS Ambarlı Fuel-Oil Thermal Power Plant turbines&generators of units 1-2-3. Condition monitoring for the application was limited to turbine cycles, bearing temperatures, vibration amplitudes and active power outputs. The real data gathered at the dates between 01.12.2008 – 04.12.2008 was processed and the trend changes were analysed to create a correlation and fault table with the guidance of expert interpretations.

The data processed with the help of simple outlier removal and wavelet based de-noising with a use of multi-resolution wavelet transform. Processed data were analysed with expert interpretations, and resulted a fault and correlation table.

This work is a wide range study over power plants and condition monitoring. Practical data processing and analysis results showed that analysing trends can help recognising the faults and errors.

ELEKTRİK SANTRALİ TÜRBİN DURUM İZLEME İÇİN UYGULAMALI VERİ İŞLEME VE ANALİZİ

ÖZET

Bakım geliştikçe, yeni teknikler ortaya çıkmaktadır. Bakım konuları üzerine önemli konulardan biri ise durum izlemedir. Verimli ve ekonomik olan öngörülü bakım teknikleri, durum izleme yardımı ile makinelere uygulanabilir. Verim ve ekonomiden bahsederken, elektrik santrallerinin genelde hem ekonomik hem stratejik rolü olan büyük hacimli sanayi kuruluşlarından biri olduğunu hatırlatmak gereklidir. Bu, yüksek verimli bakım yöntemlerinin kullanılması için elektrik santrallerini öncelikli bir ortam yapar. Dahası, elektrik santralleri saf mekanik parçalardan, karmaşık elektro-mekanik parçalara uzanan pek çok bileşenlere sahiptir. Bir elektrik santralinin en kritik bileşeni türbin&jeneratör kompleksi olup, bu bileşen güvenlik ve santral verimi açısından her zaman iyi bir durumda olmalıdır.

Elektrik santrallerinde mekatronik parçalar, veri işleme ve analizi üzerinde uygulama deneyimi için bu çalışma; santral araştırmaları, bir veri toplama sistemi geliştirilmesi, veri dönüştürme, yazılım, veri işleme ve veri analizi konularını içermektedir.

Termik santraller ve bileşenleri hakkında kısaca yapılan bilgilendirmeyi, aktif çalışan bir santralde: EUAŞ Ambarlı Fuel-Oil Termik Santrali 1-2-3 üniteler türbin&jeneratöründe bulunan durum izleme sistemi takip etmiştir. Bu durum izleme sistemi, türbin devri, yatak sıcaklıkları, titreşim genlikleri ve aktif güç çıkışı ölçümleri ile sınırlanmıştır. 01.12.2008 – 04.12.2008 tarihleri arasında alınan gerçek veriler, uzman yorumları rehberliğinde veriler arası ilişki ve arıza tablosu oluşturma amacıyla işlenmiş ve trend değişimleri analiz edilmiştir.

Veriler temel hatalı veri ayıklama tekniği ve dalga formu tabanlı gürültü ayıklama yöntemlerinden çok çözünürlüklü dalga formu dönüşümü ile işlenmiştir. İşlenen veri uzman görüşleri ile analiz edilerek bir arıza ve ilişki tablosu oluşturulmuştur.

Bu çalışma elektrik santralleri ve durum izleme üzerine geniş çaplı bir araştırmadır. Ayrıca, uygulamalı veri işleme ve analizi de, trend analizinin arızaları ve hataları fark etmede yardımcı olduğunu göstermiştir.

1. INTRODUCTION

Today, electricity is one of the most common and needed power sources. At home, industry or in a simple birthday party, electricity is indispensable. As years after the invention of electricity, humankind developed ways to produce it in a continuous and controlled method. The most common energy source is thermal power plants; therefore this study will be focused on a thermal power plant.

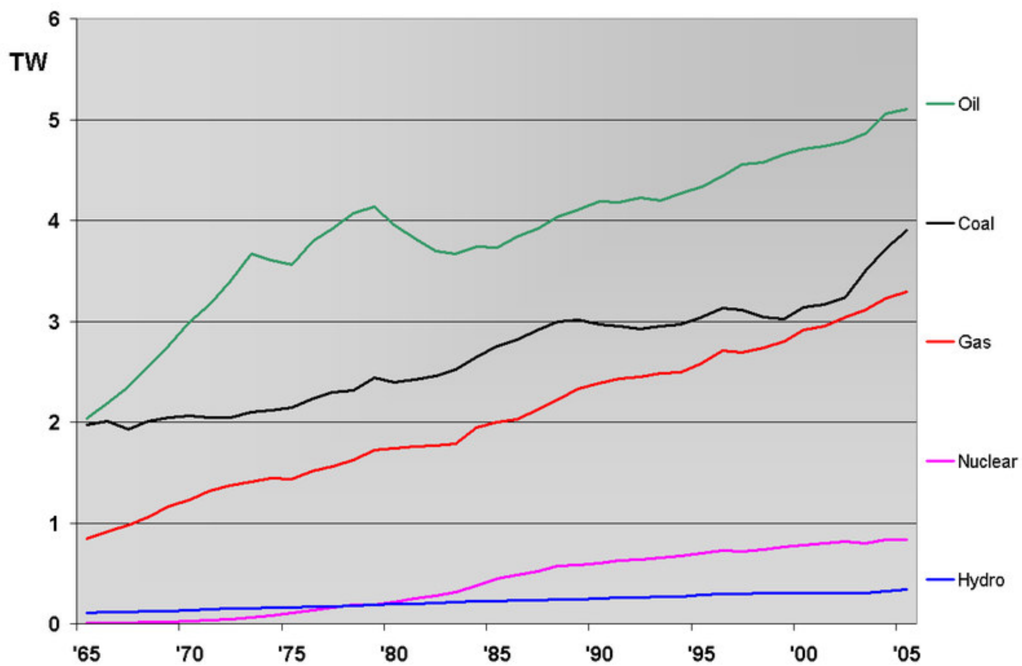


Figure 1. 1 : Total electrical power production over the world [1].

A thermal power plant is simply a facility which converts fossil fuel to electric energy via thermal process. In this process, power plants use a lot of components ranging from pure mechanical parts to complex electro-mechanical ones. Each component has its own type of maintenance needs, and own general fault types. Both to control the process, and keep the maintenance running effectively, the system needs to be monitored.

System monitoring of the plants and components creates the opportunity to gather the information about the health of the machinery. Processed information about the machinery health leads to condition monitoring techniques.

From time to time, engineers developed more effective ways to maintain a plant with using condition monitoring techniques. Instead of just using preventative maintenance, it is possible to foresee the faults and maintain the machinery when needed with the help of condition monitoring.

Signal based analysis of machinery can be used for foreseeing the faults of machinery. Addition to this, trend inspection of the signals can be a good source for a large scale system consist of a lot of components. Considering a power plant, it is good to have a trend viewing tool for gathering information about the plant condition, while having small scale machine based signal analysis for individual fault recognising.

In the last years, maintenance management became more and more strategic, so that condition monitoring and trend analysis became important. To perform that trend analysis, different signal analysis methods are subjected.

This work will focus on signal based condition monitoring and some signal analysis methods on a thermal power plant.

1.1 Roadmap

The idea of using condition monitoring techniques comes from the predictive maintenance strategy. Predictive maintenance is a highly cost effective method to keep a plant running efficiently and continuously. Especially a power plant is generally not only a commercial establishment, also a strategic one; that makes the continuity and management more important. Also power plants include so much great mechanical and mechatronical components to work for.

This work started with the idea of the condition monitoring and its techniques over predictive maintenance. After inspecting some of the methods, the work focused on power plants for application because of their great area of mechanical and mechatronical applications. In order to work on a power plant, power plants and their components inspected in a brief way. To have an application, EUAS Ambarlı Fuel-Oil Plant selected for work, and the inspection scale expanded. Because of the plant's privacy, safety and management issues, a total different data gathering system developed for the application. The collected data were stored in different formats and mediums until merged into a same format in MatLab workspace. After the data processing, the trends analysed and changes matched with the physical changes and consulted expert guidance to create a fault table.

1.2 Purpose of the Thesis

This work focuses on the practice of condition monitoring and data processing with analysis application on a power plant. As an objective, the plant will be identified, as well as the data acquisition system will be inspected and a small scale data gathering system will be developed. With the help of the data collected, an expert guided fault table will be seeked according to the inspection of the trends of data gathered. Also, this work can be expanded to a level of full system monitoring with a learning algorithm in a doctorate – post doctorate level.

1.3 Hypothesis

This study provided an opportunity to gather information about the upcoming faults by inspecting the trends of the data of turbine cycles, bearing temperatures, vibrations and the correlation with the power output while consulting expert guidance for previous similar situations and faults.

2. POWER PLANTS AND COMPONENTS

A power station (also referred to as a generating station, power plant, or powerhouse) is an industrial facility for the generation of electric power [2-4].

At the center of nearly all power stations is a generator, a rotating machine that converts mechanical energy into electrical energy by creating relative motion between a magnetic field and a conductor. The energy source harnessed to turn the generator varies widely. It depends chiefly on which fuels are easily available and on the types of technology that the power company has access to.

2.1 General Overview to Thermal Power Plants

A thermal power station is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser; this is known as a Rankine cycle. The greatest variation in the design of thermal power stations is due to the different fuel sources. Some prefer to use the term *energy center* because such facilities convert forms of heat energy into electrical energy.

Almost all coal, nuclear, geothermal, solar thermal electric and waste incineration plants, as well as many natural gas power plants are thermal. Natural gas is frequently combusted in gas turbines as well as boilers. The waste heat from a gas turbine can be used to raise steam, in a combined cycle plant that improves overall efficiency.

Such power stations are most usually constructed on a very large scale and designed for continuous operation.

2.2 Main Components of Thermal Power Plants

2.2.1 Steam generator

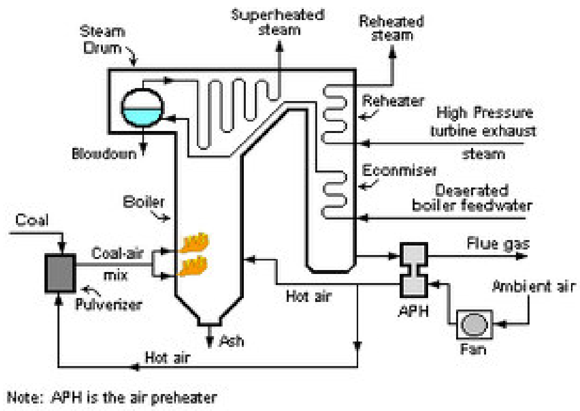


Figure 2. 1 : Schematic diagram of typical coal-fired power plant steam generator.

The steam generating boiler has to produce steam at the high purity, pressure and temperature required for the steam turbine that drives the electrical generator. The generator includes the economizer, the steam drum, the chemical dosing equipment, and the furnace with its steam generating tubes and the superheater coils. Necessary safety valves are located at suitable points to avoid excessive boiler pressure. The air and flue gas path equipment include: forced draft (FD) fan, air preheater (APH), boiler furnace, induced draft (ID) fan, fly ash collectors (electrostatic precipitator or baghouse) and the flue gas stack [2-4].

For units over about 200 MW capacity, redundancy of key components is provided by installing duplicates of the FD fan, APH, fly ash collectors and ID fan with isolating dampers. On some units of about 60 MW, two boilers per unit may instead be provided.

2.2.1.1 Boiler furnace and steam drum

Once water inside the boiler or steam generator, the process of adding the latent heat of vaporization or enthalpy is underway. The boiler transfers energy to the water by the chemical reaction of burning some type of fuel.

The water enters the boiler through a section in the convection pass called the economizer. From the economizer it passes to the steam drum. Once the water enters the steam drum it goes down the downcomers to the lower inlet waterwall headers. From the inlet headers the water rises through the waterwalls and is eventually turned into steam due to the heat being generated by the burners located on the front and rear waterwalls (typically). As the water is turned into steam/vapor in the waterwalls, the steam/vapor once again enters the steam drum. The steam/vapor is passed through a series of steam and water separators and then dryers inside the steam drum. The steam separators and dryers remove the water droplets from the steam and the cycle through the waterwalls is repeated. This process is known as natural circulation.

The boiler furnace auxiliary equipment includes coal feed nozzles (liquid fuel nozzles for petrol based plants) and igniter guns, soot blowers, water lancing and observation ports (in the furnace walls) for observation of the furnace interior. Furnace explosions due to any accumulation of combustible gases after a trip-out are avoided by flushing out such gases from the combustion zone before igniting the coal.

The steam drum (as well as the superheater coils and headers) have air vents and drains needed for initial startup. The steam drum has internal devices that removes moisture from the wet steam entering the drum from the steam generating tubes. The dry steam then flows into the superheater coils.

Geothermal plants need no boiler since they use naturally occurring steam sources. Heat exchangers may be used where the geothermal steam is very corrosive or contains excessive suspended solids. Nuclear plants also boil water to raise steam, either directly passing the working steam through the reactor or else using an intermediate heat exchanger.

2.2.1.2 Fuel preparation system

In coal-fired power stations, the raw feed coal from the coal storage area is first crushed into small pieces and then conveyed to the coal feed hoppers at the boilers. The coal is next pulverized into a very fine powder. The pulverizers may be ball mills, rotating drum grinders, or other types of grinders.

Some power stations burn fuel oil rather than coal. The oil must kept warm (above its pour point) in the fuel oil storage tanks to prevent the oil from congealing and becoming unpumpable. The oil is usually heated to about 100°C before being pumped through the furnace fuel oil spray nozzles.

Boilers in some power stations use processed natural gas as their main fuel. Other power stations may use processed natural gas as auxiliary fuel in the event that their main fuel supply (coal or oil) is interrupted. In such cases, separate gas burners are provided on the boiler furnaces.

2.2.1.3 Air path

External fans are provided to give sufficient air for combustion. The forced draft fan takes air from the atmosphere and, first warming it in the air preheater for better combustion, injects it via the air nozzles on the furnace wall.

The induced draft fan assists the FD fan by drawing out combustible gases from the furnace, maintaining a slightly negative pressure in the furnace to avoid backfiring through any opening. At the furnace outlet, and before the furnace gases are handled by the ID fan, fine dust carried by the outlet gases is removed to avoid atmospheric pollution. This is an environmental limitation prescribed by law, and additionally minimizes erosion of the ID fan.

2.2.1.4 Auxiliary systems

Fly ash collection:

Fly ash is captured and removed from the flue gas by electrostatic precipitators or fabric bag filters (or sometimes both) located at the outlet of the furnace and before the induced draft fan. The fly ash is periodically removed from the collection hoppers below the precipitators or bag filters. Generally, the fly ash is pneumatically transported to storage silos for subsequent transport by trucks or railroad cars.

Bottom ash collection and disposal:

At the bottom of every boiler, a hopper has been provided for collection of the bottom ash from the bottom of the furnace. This hopper is always filled with water to quench the ash and clinkers falling down from the furnace. Some arrangement is included to crush the clinkers and for conveying the crushed clinkers and bottom ash to a storage site.

Boiler make-up water treatment plant and storage:

Since there is continuous withdrawal of steam and continuous return of condensate to the boiler, losses due to blow-down and leakages have to be made up for so as to maintain the desired water level in the boiler steam drum. For this, continuous make-up water is added to the boiler water system. The impurities in the raw water input to the plant generally consist of calcium and magnesium salts which impart hardness to the water. Hardness in the make-up water to the boiler will form deposits on the tube water surfaces which will lead to overheating and failure of the tubes. Thus, the salts have to be removed from the water and that is done by a water demineralising treatment plant (DM). A DM plant generally consists of cation, anion and mixed bed exchangers. The final water from this process consists essentially of hydrogen ions and hydroxide ions which is the chemical composition of pure water. The DM water, being very pure, becomes highly corrosive once it absorbs oxygen from the atmosphere because of its very high affinity for oxygen absorption.

The capacity of the DM plant is dictated by the type and quantity of salts in the raw water input. However, some storage is essential as the DM plant may be down for maintenance. For this purpose, a storage tank is installed from which DM water is continuously withdrawn for boiler make-up. The storage tank for DM water is made from materials not affected by corrosive water, such as PVC. The piping and valves are generally of stainless steel. Sometimes, a steam blanketing arrangement or stainless steel doughnut float is provided on top of the water in the tank to avoid contact with atmospheric air. DM water make-up is generally added at the steam space of the surface condenser (i.e., the vacuum side). This arrangement not only sprays the water but also DM water gets deaerated, with the dissolved gases being removed by the ejector of the condenser itself.

2.2.2 Steam turbine-driven electric generator

Figure 2. 2 : Rotor of a modern steam turbine, used in a power station.

The steam turbine-driven generators have auxiliary systems enabling them to work satisfactorily and safely. The steam turbine generator being rotating equipment generally has a heavy, large diameter shaft. The shaft therefore requires not only supports but also has to be kept in position while running. To minimise the frictional resistance to the rotation, the shaft has a number of bearings. The bearing shells, in which the shaft rotates, are lined with a low friction material like Babbitt metal. Oil lubrication is provided to further reduce the friction between shaft and bearing surface and to limit the heat generated.

2.2.2.1 Barring gear

Barring gear (or "turning gear") is the mechanism provided to rotate the turbine generator shaft at a very low speed after unit stoppages. Once the unit is "tripped" (i.e., the steam inlet valve is closed), the turbine coasts down towards standstill. When it stops completely, there is a tendency for the turbine shaft to deflect or bend if allowed to remain in one position too long. This is because the heat inside the turbine casing tends to concentrate in the top half of the casing, making the top half portion of the shaft hotter than the bottom half. The shaft therefore could warp or bend by millionths of inches.

This small shaft deflection, only detectable by eccentricity meters, would be enough to cause damaging vibrations to the entire steam turbine generator unit when it is restarted. The shaft is therefore automatically turned at low speed (about one revolution per minute) by the barring gear until it has cooled sufficiently to permit a complete stop.

2.2.2.2 Condenser

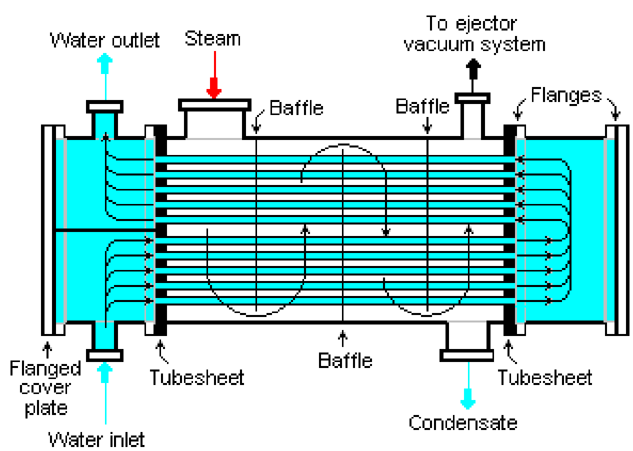


Figure 2. 3 : Diagram of a typical water-cooled surface condenser [3-6].

The surface condenser is a shell and tube heat exchanger in which cooling water is circulated through the tubes [3,5-7]. The exhaust steam from the low pressure turbine enters the shell where it is cooled and converted to condensate (water) by flowing over the tubes as shown in the adjacent diagram. Such condensers use steam ejectors or rotary motor-driven exhausters for continuous removal of air and gases from the steam side to maintain vacuum.

For best efficiency, the temperature in the condenser must be kept as low as practical in order to achieve the lowest possible pressure in the condensing steam. Since the condenser temperature can almost always be kept significantly below 100 ^{o}C where the vapor pressure of water is much less than atmospheric pressure, the condenser generally works under vacuum. Thus leaks of non-condensible air into the closed loop must be prevented. Plants operating in hot climates may have to reduce output if their source of condenser cooling water becomes warmer; unfortunately this usually coincides with periods of high electrical demand for air conditioning.

The condenser generally uses either circulating cooling water from a cooling tower to reject waste heat to the atmosphere, or once-through water from a river, lake or ocean.

2.2.2.3 Feedwater heater

In the case of a conventional steam-electric power plant utilizing a drum boiler, the surface condenser removes the latent heat of vaporization from the steam as it changes states from vapour to liquid. The heat content (btu) in the steam is referred to as Enthalpy. The condensate pump then pumps the condensate water through a feedwater heater. The feedwater heating equipment then raises the temperature of the water by utilizing extraction steam from various stages of the turbine [3,4].

Preheating the feedwater reduces the irreversibilities involved in steam generation and therefore improves the thermodynamic efficiency of the system [8]. This reduces plant operating costs and also helps to avoid thermal shock to the boiler metal when the feedwater is introduced back into the steam cycle.

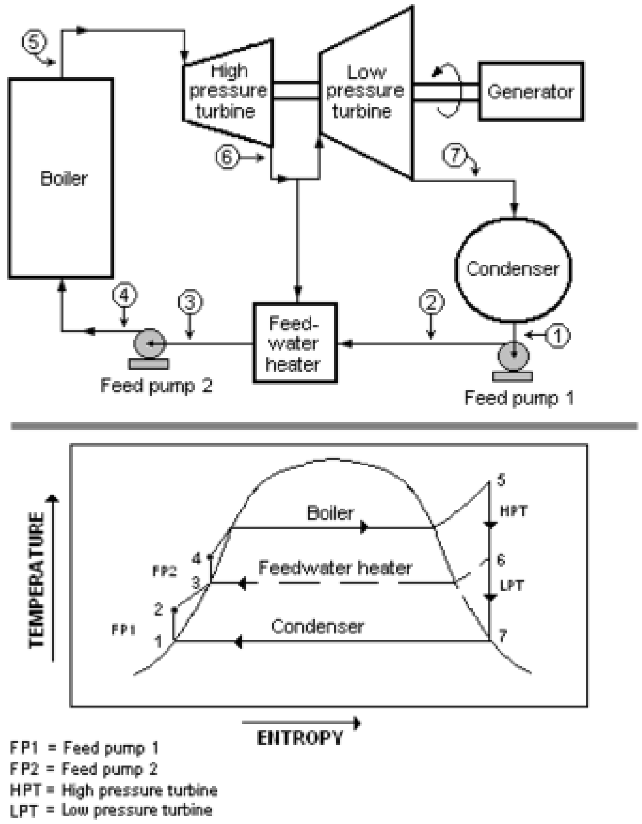


Figure 2. 4 : A Rankine cycle with two-stage steam turbine.

2.2.2.4 Superheater

As the steam is conditioned by the drying equipment inside the drum, it is piped from the upper drum area into an elaborate set up of tubing in different areas of the boiler. The areas known as superheater and reheater. The steam vapor picks up energy and its temperature is now superheated above the saturation temperature. The superheated steam is then piped through the main steam lines to the valves of the high pressure turbine.

2.2.2.5 Dearator

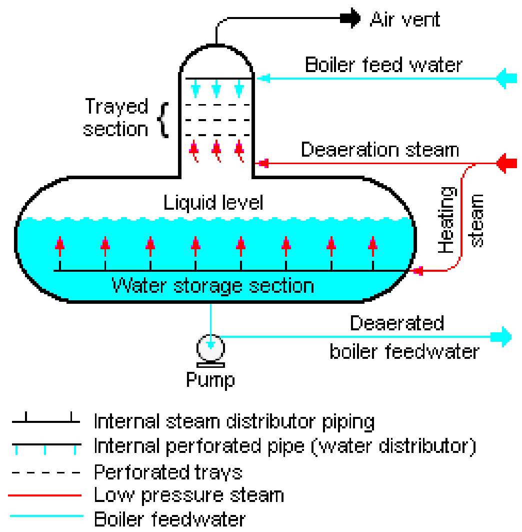


Figure 2. 5 : Diagram of boiler feed water deaerator.

A steam generating boiler requires that the boiler feed water should be devoid of air and other dissolved gases, particularly corrosive ones, in order to avoid corrosion of the metal.

Generally, power stations use a deaerator to provide for the removal of air and other dissolved gases from the boiler feedwater. A deaerator typically includes a vertical, domed deaeration section mounted on top of a horizontal cylindrical vessel which serves as the deaerated boiler feedwater storage tank [3,4,9].

There are many different designs for a deaerator and the designs will vary from one manufacturer to another. The adjacent diagram depicts a typical conventional trayed deaerator.[9,10] If operated properly, most deaerator manufacturers will guarantee that oxygen in the deaerated water will not exceed 7 ppb by weight (0.005 cm^3/L) [9,11].

2.2.2.6 Auxiliary systems

Oil system:

An auxiliary oil system pump is used to supply oil at the start-up of the steam turbine generator. It supplies the hydraulic oil system required for steam turbine's main inlet steam stop valve, the governing control valves, the bearing and seal oil systems, the relevant hydraulic relays and other mechanisms.

At a preset speed of the turbine during start-ups, a pump driven by the turbine main shaft takes over the functions of the auxiliary system.

Generator heat dissipation:

The electricity generator requires cooling to dissipate the heat that it generates. While small units may be cooled by air drawn through filters at the inlet, larger units generally require special cooling arrangements. Hydrogen gas cooling, in an oil-sealed casing, is used because it has the highest known heat transfer coefficient of any gas and for its low viscosity which reduces windage losses. This system requires special handling during start-up, with air in the chamber first displaced by carbon dioxide before filling with hydrogen. This ensures that the highly flammable hydrogen does not mix with oxygen in the air.

The hydrogen pressure inside the casing is maintained slightly higher than atmospheric pressure to avoid outside air ingress. The hydrogen must be sealed against outward leakage where the shaft emerges from the casing. Mechanical seals around the shaft are installed with a very small annular gap to avoid rubbing between the shaft and the seals. Seal oil is used to prevent the hydrogen gas leakage to atmosphere.

The generator also uses water cooling. Since the generator coils are at a potential of about 22 kV and water is conductive, an insulating barrier such as Teflon is used to interconnect the water line and the generator high voltage windings. Demineralized water of low conductivity is used.

Generator high voltage system:

The generator voltage ranges from 11 kV in smaller units to 22 kV in larger units. The generator high voltage leads are normally large aluminum channels because of their high current as compared to the cables used in smaller machines. They are enclosed in well-grounded aluminum bus ducts and are supported on suitable insulators. The generator high voltage channels are connected to step-up transformers for connecting to a high voltage electrical substation (of the order of 110 kV or 220 kV) for further transmission by the local power grid.

The necessary protection and metering devices are included for the high voltage leads. Thus, the steam turbine generator and the transformer form one unit. In smaller units, generating at 11 kV, a breaker is provided to connect it to a common 11 kV bus system.

2.2.3 Other systems

2.2.3.1 Monitoring and alarm system

Most of the power plant operational controls are automatic. However, at times, manual intervention may be required. Thus, the plant is provided with monitors and alarm systems that alert the plant operators when certain operating parameters are seriously deviating from their normal range.

2.2.3.2 Battery supplied emergency lighting and communication

A central battery system consisting of lead acid cell units is provided to supply emergency electric power, when needed, to essential items such as the power plant's control systems, communication systems, turbine lube oil pumps, and emergency lighting. This is essential for a safe, damage-free shutdown of the units in an emergency situation.

2.3 Ambarlı Fuel-Oil Thermal Power Plant

Ambarlı Fuel-Oil Thermal Power Plant was founded in February 1967 at the 30km west of Istanbul near Marmara sea shore with two equal units of 110MWs. After 3 years at August 1970 an equal third unit added to the plant while in one year two 150MWs different units added too.

The first 3 units are designs for desert environment and uses old technology. However, it is a good environment to have fault researches because of its availability to install newer equipments due to lack of up-to-date embadled monitoring and control systems. Also, the plant has a lot of faults to research for [12].

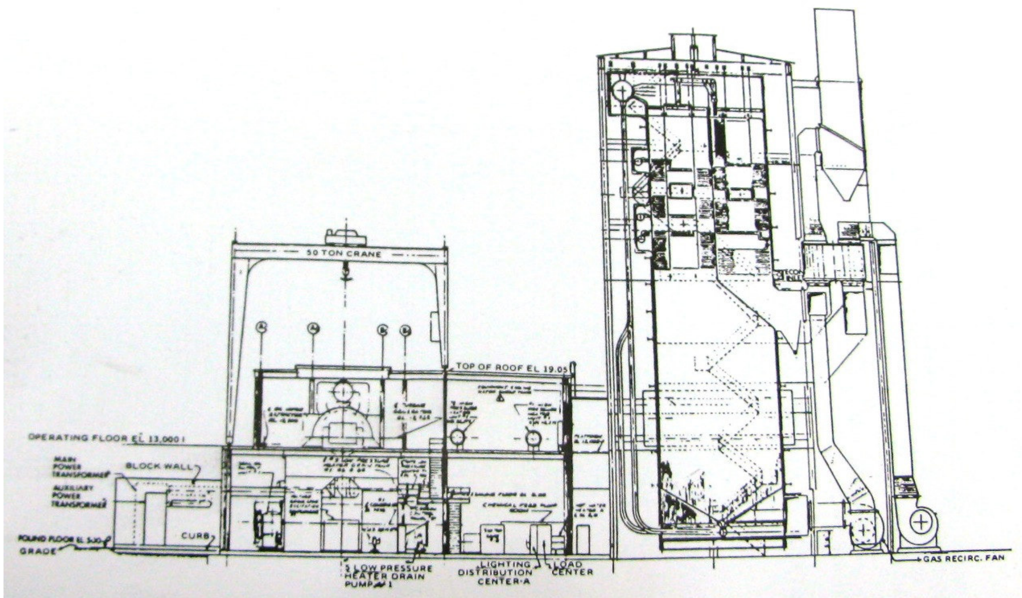


Figure 2. 6 : Schema of Ambarlı power plant units 1-2-3.

2.3.1 Main components

The main components of Ambarlı Fuel-oil Power Plant can be inspected under 5 headlines. The Boilers, the Turbines, The Condenser and Auxiliary Parts, The Generator and The Transformer. However the plant has 5 units, this work includes only the 1-2-3 units which have the same structure, and negate the units 4-5 which has a different type and structure from the first 3 units [12].

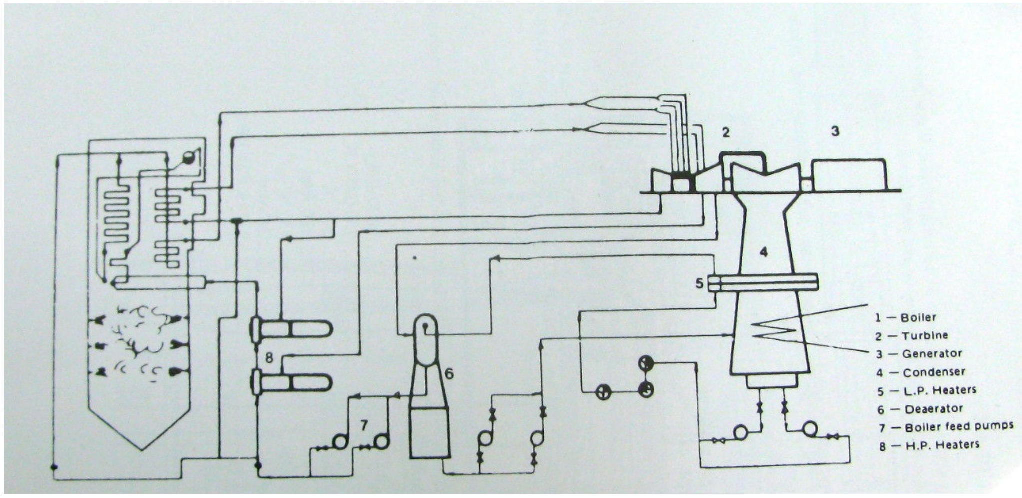


Figure 2. 7 : The water-steam cycle for Ambarlı plant.

2.3.1.1 The boilers

The Combustion Engineering brand boilers have natural circulation and tangential mechanical fuel injected burners. The steam separated with one single drum, while it is reheated with a one level reheater. The construction of boilers are desert type, without a closure building because of the air circulation is forced inside the furnace [12].

Table 2. 1: Boiler parameters

Parameter	Value
Drum Pressure	132 kg/cm^2
Superheated/Reheated Steam Temperature	540^{o}C/540^{o}C
Flow	362 t/h
First fuel	Diesel
Continuous fuel	Fuel-Oil (10,000 kcal/kg)
Burners per boiler	12 (tangential layout - 3 layers)
Furnace pressure	+450-500 mm fluid height
Fuel consumption	26.6 t/h

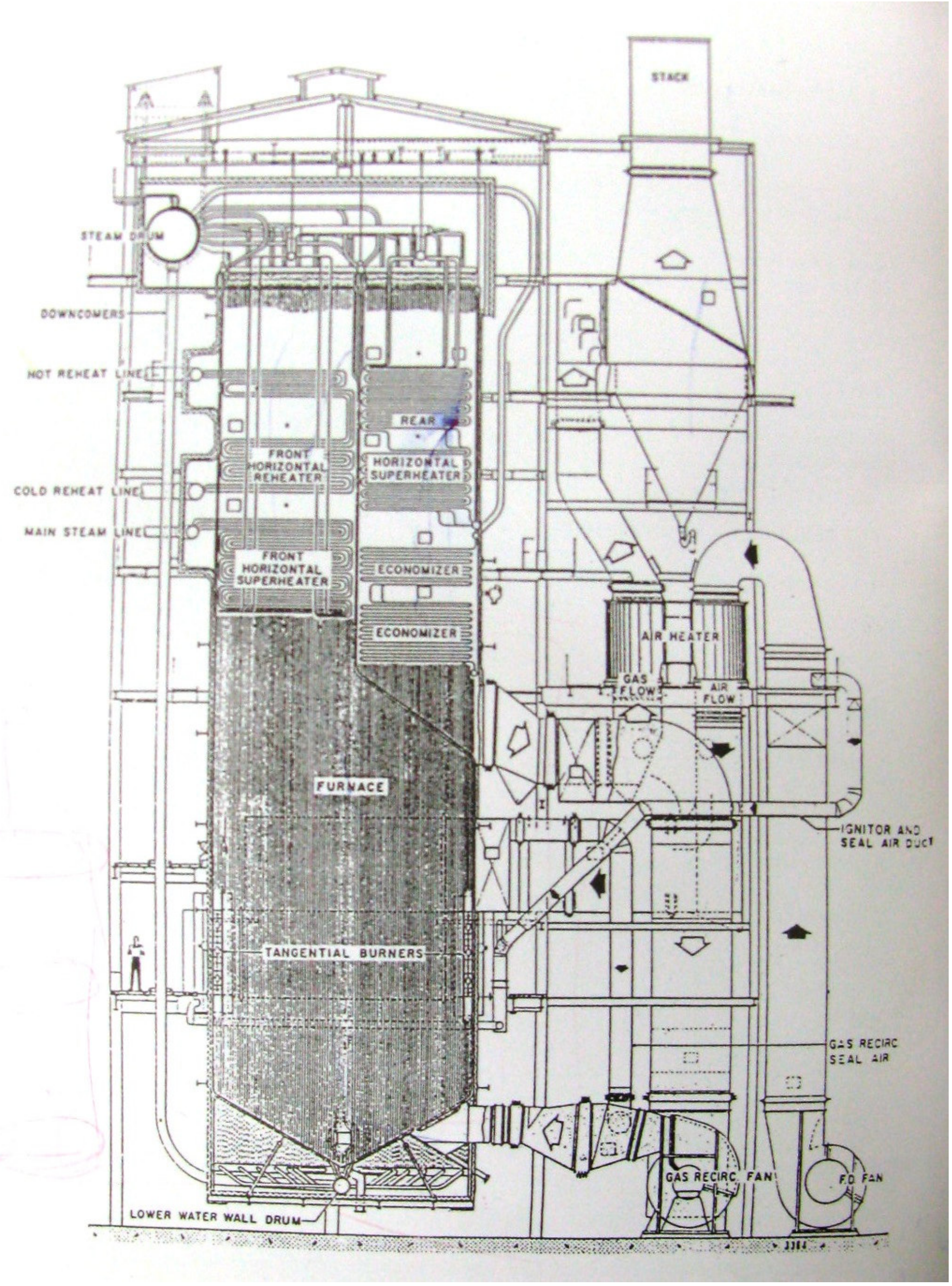


Figure 2. 8 : Boiler and furnice in Ambarlı plant.

2.3.1.2 The turbines

The Westinghouse (GE for 3rd Turbine) steam turbines has 3 pressure levels with dual steam exhausts. Also the turbines are one axis, condensation type [12].

Table 2. 2: Turbine parameters

Paramters	Value
Power Output	110 MW
Cycles	3000 rpm
Steam Input Temperature	538^{o}C
Steam Input Pressure	126.5 kg/cm^2
Reheated Steam Temparature	538^{o}C
Reheated Steam Pressure	30 kg/cm^2
Exhaust Pressure	38 mm Hg / 20^{o}C
Heat Consumption	2459 k Cal / kWh

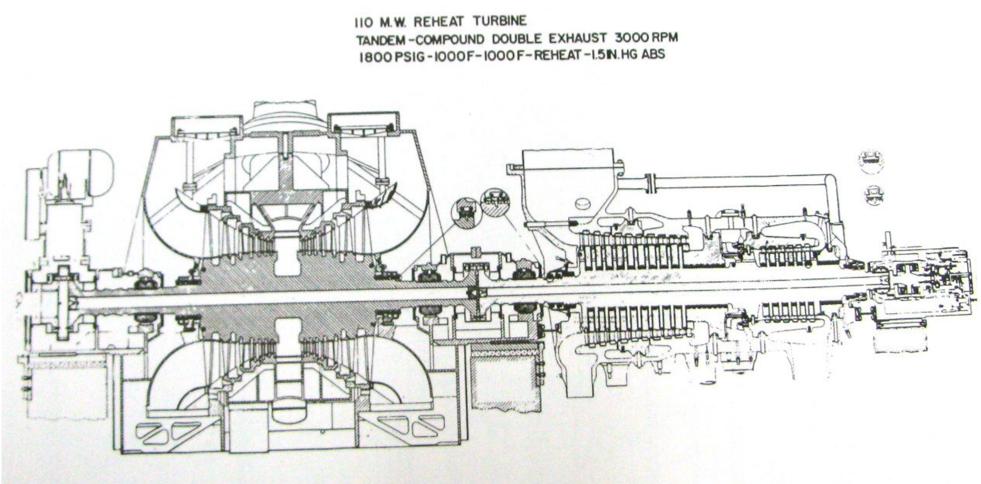


Figure 2. 9 : Steam turbine of unit 1-2-3 in Ambarlı plant.

2.3.1.3 Condensers

Condensers are one way pass, two sectioned water cooled type.

Table 2. 3: Condenser parameters

Parameters	Value
Cooling Liquid	Marmara Sea Water
Tube Numbers	7000
Tube Diameter	25mm
Tube Material	Aluminium Brass
Condenser Total Cooling Area	5109 m^2
Ejector	2 level
Number of Cooling Water Pumps	2 per Unit
Cooling Water Pump Flow	10,680 t/h
Cooling Water Output Pressure	7.1 mt. fluid height

2.3.1.4 Generators

Three phase, hydrogen cooled generators of brands Westinghouse (GE for 3rd unit).

Table 2. 4: Generator parameters

Parameters	Value
Power (Under 2.1 kg/cm^2 Hydrogen Pressure)	133.689 kVA
Output Voltage	13,800 V
Current	5,593 A
Frequency	50 Hz
Power Factor	0.85
Excitement Voltage	375 V

2.3.1.5 Transformers

Each unit has one main transformer for power output, and one self-need 8,400 kVA transformer. Also there is a 14,000 kVA start-up transformer for all three units [12].

Main Transformers:

Table 2. 5: Main transformer parameters

Parameters	Value
Continuous Power	134.000 kVA (65^{o}C)
Phase	3
Primer Voltage	13.8 kV (Triangle)
Secondary Voltage	161 kV (Star)
Level	%2x2.5

2.3.2 Components of interest

This work focuses on the Turbine-Generator Complex due to its importance on the plant and fault characteristics. However, each component of the plant has a large or small effect on the whole system. This is so all main plant components informed in this work.

The turbine&generator complex running condition can be monitored with the measures of some parameters. In this work, turbine cycles, bearing temperatures, and bearing vibrations are selected as condition monitoring data. As well as these important tracked data, information of eccentricity, oil pressures and some other parameters of turbines are being measured by the plant operators, however, this work doesn't include them as a direct input.

3. DATA ACQUISITION FOR AMBARLI FUEL-OIL POWER PLANT

The control room is the centre for data acquisition and monitoring while there is also other small-scale data monitoring panels over the plant components.

Figure 3. 1 : Control room of Ambarlı plant of units 1-2-3.

3.1 General Overview to Data Monitoring Systems in Ambarlı Plant

The first control room has the monitoring and control systems for units 1-2-3. There is also a second control room for units 4-5 which has different structure than the first 3 units. Also the subsystems of the plant have different control and monitoring panels such as shore cooling water subsystem. The system of interest is turbine-generator complex, so the data acquiring of turbine vibrations, bearing temperature and revolution will inspected in this work. In addition to these data, a correlation will be seeked with these data and power output.

3.2 Digital Monitoring System of Interest

In this work, the correlation between the vibration amplitude, turbine cycles, bearing temperature and power output data will be inspected. In order to do this work, the data gathered from two different data monitors. For the vibration amplitude, turbine cycles and bearing temperature, a data acquisition and logger system arranged while the power output data gathered over internet. The power output data wasn't able to be gathered directly because of the encoding of pre-defined monitoring system. For the security and privacy of the plant, it was impossible to make a change in this system.

3.2.1 Data logging system for vibrations, cycles and temperatures

The vibration amplitude, turbine cycles and bearing temperature of the turbines for 1-2-3 units in the plant were stored in a recorder manufactured by Elimko firm. In this chapter, the recording and monitoring system will be briefly described.

Figure 3. 2 : The data recorder device and the attached PC.

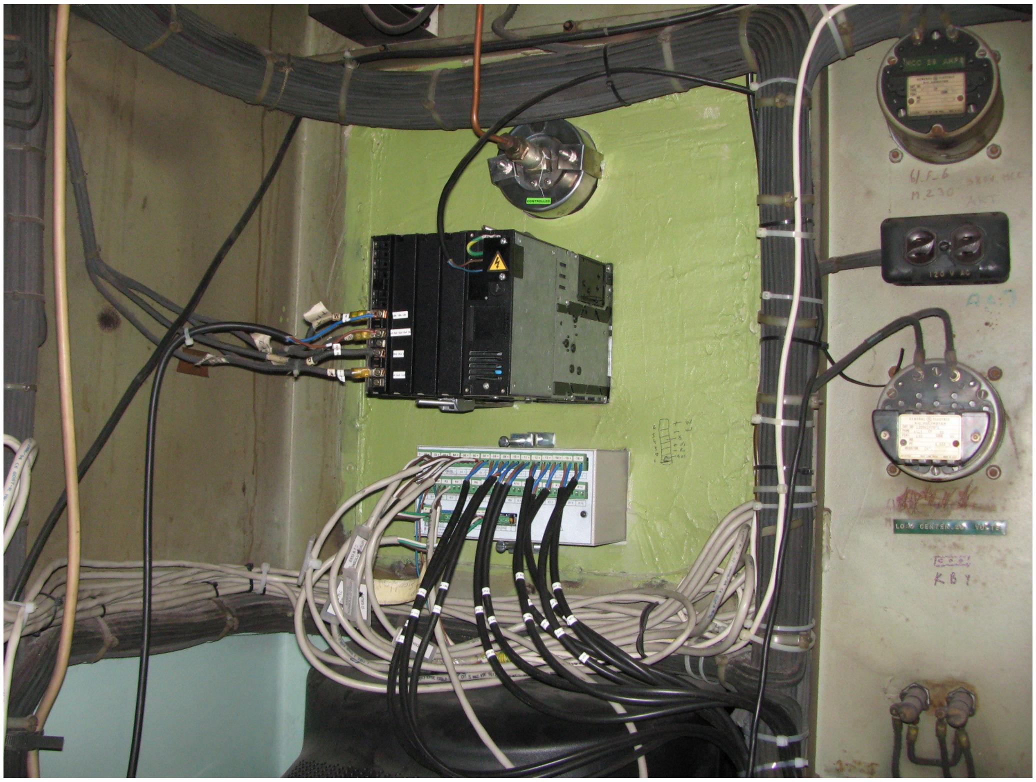


Figure 3. 3 : Backview of data recorder.

The recorder has 16 data inputs and 16 relay outputs. The inputs were used to gather the vibration amplitude, turbine cycles and bearing temperature. Turbine cycles and bearing temperature gathered from Siemens sensors producing 4-20 mA, while vibration data gathered from vibration sensors of Westinghouse producing 0-40 mV. Each data set to log in each 1 second, thus make the inspection a low-sampling ratio work.

3.2.1.1 Turbine cycles and temperature sensors

The turbine cycles measured with a disk with one black point and an optical probe. Each cycle creates a signal from the probe to amplifier which has an electronic circuitry conditioning the signal as cycles to an output of 4-20 mA.

As cycle measurements, temperature sensor amplifiers have the same output of 4-20 mA. The temperature measured by a thermo-couple and signal conditioning is made in its amplifier card. The bearing temperatures are taken between from the generator side, while other bearings are also measured but not logged by the data recorder device.

3.2.1.2 Vibration sensors

The vibration sensors are consist of several parts. The pick-up base touches the shaft of the turbine, while the pick-up head has the electromagnetic structure which produces A.C signal according to the speed and vertical movements (vibration) of the shaft. The structure can be simplified as a moving coil inside a magnetic field. The electronic circuitry of the sensor includes a plug-in amplifier which converts the A.C. signal to D.C 0-40 mV for a double amplitude range of vibration of 0-15 mili Inches (381 micron) by integrating the incoming A.C. signal from the head. There is drawer included in the system for recording the vibration of the turbines; however, to inspect the data in a computer environment, the sensor outputs were connected to a digital recorder mentioned above.

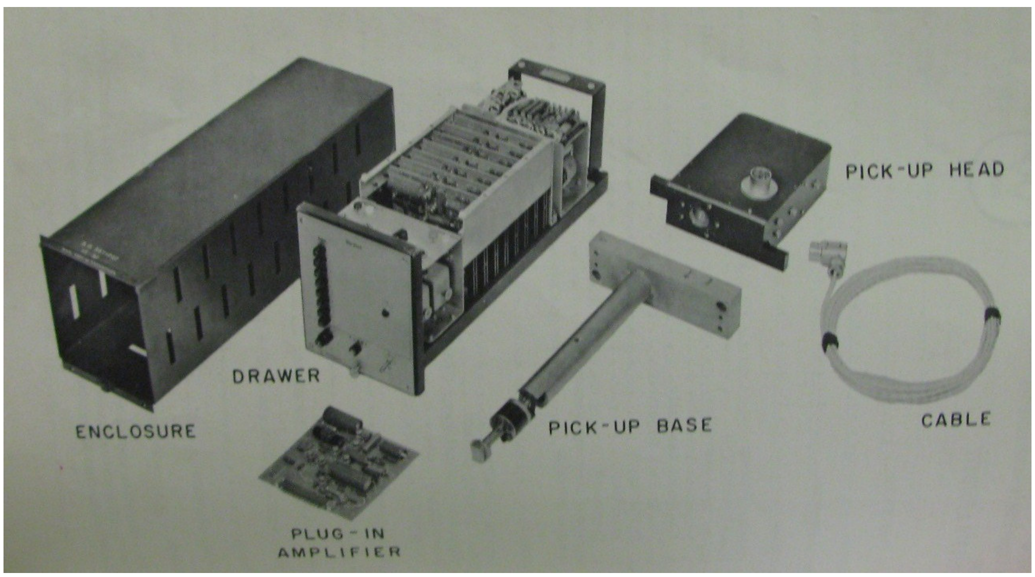


Figure 3. 4 : Vibration sensors.

3.2.2 Power output data monitoring system

When this work was started, there was already a power output monitoring system separately implemented. In order to track the power output, the general director's office of the company had set a digital recorder and an internet structure to monitor the power output in internet environment. Because of the privacy and security of the plant and commercial issues, it was impossible to get the data directly. It was also unnecessary to create a completely new system for the power output data gathering, so a software created to log the power output over internet.

The default internet structure is based on an xml server which has the access to the power recorder database. Also, the internet site has access only to internal IP numbers for the plant itself. The software written for this work, accesses the data over the site itself, while updating the data approximately every 6 seconds and logs the data of date & time and power outputs to a text file. The default internet and server subfracture was barely enough to handle this frequency of approximately 6 seconds; however, there is no much need to gather a more frequent power output data while having the other data also in a low frequency rate. The site and program screenshot are in the figures 3.5 and 3.6.

The software source code for visual basic is in the Appendix A.1

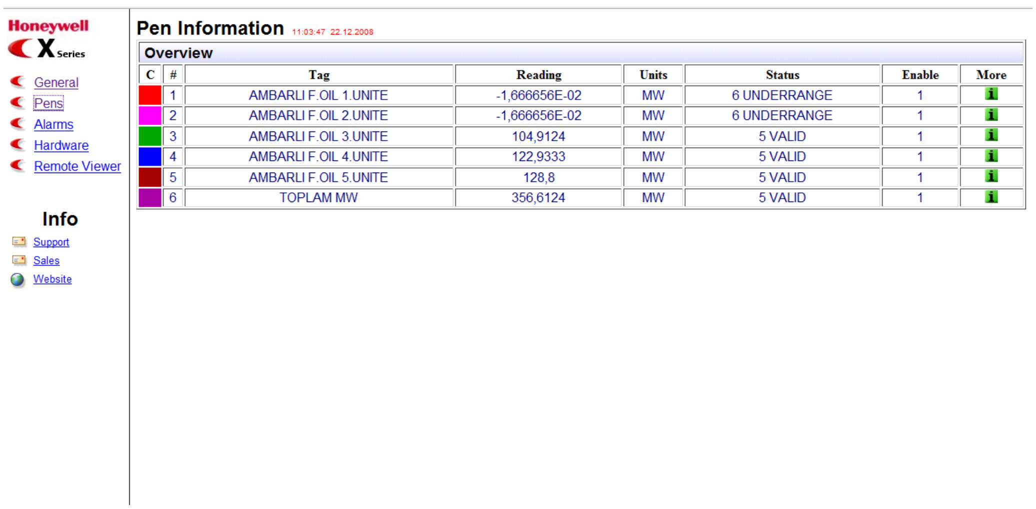


Figure 3. 5 : Internet site of plant power outputs.

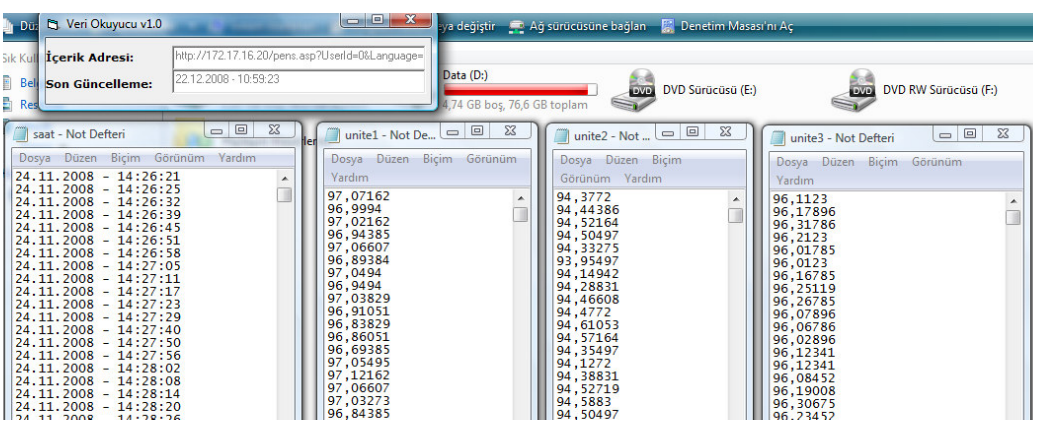


Figure 3. 6 : Screenshot of the data logger software while running.

4. SIGNAL ANALYSIS METHODS

4.1 Basic Statistical Parameters for Data Analysis

Several statistical parameters, calculated in the time domain, are generally used to define average properties of random data. The two basic parameters are the mean value, μ and the standard deviation, σ. For a given data set, $\{x_i\}$, these are defined as follows:

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i \text{ , and} \tag{4.1}$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \text{ .} \tag{4.2}$$

where N is the number of the data points.

For the Gaussian (normal) probability distribution, two parameters that reflect the departure from the normal distribution are skewness (s) and kurtosis (k). These are calculated as follows:

$$s = \frac{\left[\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \mu\right)^3\right]}{\sigma^3} \text{, and} \tag{4.3}$$

$$k = \frac{\left[\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^4\right]}{\sigma^4} \tag{4.4}$$

For a perfect normal distribution, s is equal to zero. Any positive or negative value of the *s* denotes an asymmetrical distribution. In this case, a negative value of *s* indicates skewed to the left while a positive value indicates skewed to the right. For small data sets, one often gets values that differ from zero. The kurtosis or the measure of the sharpness of the peak, *k*, is very close to three for a normal distribution. These statistical parameters may be used to perform a quick check of the changes in the statistical behaviour of a signal [13].

4.2 Data Pre-Processing: Outlier and Errored Data Removal

When you examine a data plot, you might find that some points appear to dramatically differ from the rest of the data. In some cases, it is reasonable to consider such points outliers, or data values that do not appear to be consistent with the rest of the data [14].

An outlier is defined as a value that is more than desired (generally 3 times) standard deviations away from the mean, such as the illustration below:

When an outlier is considered to be more than three standard deviations away from the mean, you can use the following steps to remove the outliers in each column of the data matrix:

Step by Step Outlier Removal for a matrix of (n x m):

1. Create a matrix of mean values by replicating the μ vector for n rows
2. Create a matrix of standard deviation values by replicating the σ vector for n rows
3. Create an outliers matrix of zeros and ones, where ones indicate the location of outliers
4. Remove the entire rows for logical one on outliers matrix.

4.3 Multi-Resolution Wavelet Transform (MRWT)

The use of the wavelet transform is particularly appropriate since it gives information about the signal both in frequency and time domains. Let *f(x)* be the signal, the continuous wavelet transform of *f(x)* is then defined as

$$W_f(a, b) = \int_{-\infty}^{+\infty} f(x)\psi_{a,b}(x)dx, \qquad \textbf{(4.5)}$$

where

$$\psi_{ab}(x) = \frac{1}{\sqrt{|a|}}\psi\left(\frac{x-b}{a}\right) \qquad a, b \in R, a \neq 0 \qquad \textbf{(4.6)}$$

such that

$$C_\psi = \int_0^{+\infty} \frac{|\psi(\omega)|^2}{\omega} d\omega \langle \infty \qquad \textbf{(4.7)}$$

and

$$\int_{-\infty}^{+\infty} \psi(x)dx = 0. \qquad \textbf{(4.8)}$$

Here $\psi(\omega)$ stands for the Fourier transform of $\psi(x)$. The admissibility condition (4) requires that the Fourier transform of $\psi(x)$ vanishes at the zero frequency. Therefore ψ is called as a wave or the mother wavelet and it have two characteristic parameters, namely, dilation (a) and translation (b), which vary continuously. The translation parameter, b, controls the position of the wavelet in time. On the other hand, a "narrow" wavelet can access high-frequency information, while a more dilated wavelet can access low-frequency information. This means that the parameter a varies with different frequency. In the discrete wavelet transform (DWT), the parameters a and b take discrete values, $a = a_0^j$, $b = nb_0 a_0^j$, where $n, j \in Z$, $a_0 > 1$, and $b_0 > 0$. The DWT is defined as [15, 16]:

$$\text{DWT}\,[j,k] = \frac{1}{\sqrt{a_0^j}} \sum_n f[n]\,\psi\left[\frac{k - n a_0^j}{a_0^j}\right] \tag{4.9}$$

4.4 A Brief Knowledge about Multi-Resolution Analysis (MRA)

S. Mallat introduced an efficient algorithm to perform the DWT known as the MRA [15]. The MRA is similar to a two-channel sub-band coder in high-pass and low-pass filters, from which the original signal can be reconstructed. Fig. 1 shows the n stage frequency decomposition of the signal schematically. The low frequency sub-band is referred to as 'approximation a_i' and the high-frequency sub-band by 'detail d_i'. Thus, the signal may be reconstructed as $S = a_n + d_1 + d_2 + \ldots + d_n$ at the nth stage.

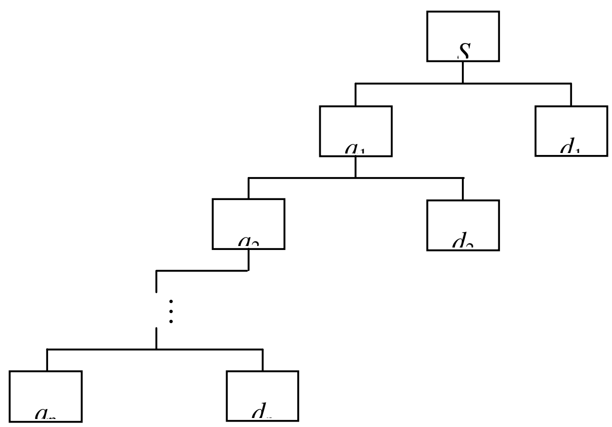


Figure 4. 1 : Signal decomposition at the nth stage.

4.5 Wavelet Based Signal De-Noising

De-Noising of a data/signal is done by decomposing the wave with an appropirate wave form and level, applying a threshold and reconstructing the wave. A step by step procedure is below:

The de-noising procedure proceeds in three steps:

1. Decomposition. Choose a wavelet, and choose a level N. Compute the wavelet decomposition of the signal s at level N.

Daubechies' mother wavelet db40 at a level 14 were chosen.

2. Detail coefficients thresholding. For each level from 1 to N, select a threshold and apply soft thresholding to the detail coefficients.

Threshold was chosen as sqrt(2*log(length(X))

3. Reconstruction. Compute wavelet reconstruction based on the original approximation coefficients of level N and the modified detail coefficients of levels from 1 to N.

The data was reconstructed as $S = a_N + d_1 + d_2 + \ldots + d_N$ at the N^{th} (N=14) level [17].

5. APPLICATION

Practical application was one of the objectives in this study. In this chapter, turbine&generator complex will be monitored with different data, and this data will be analysed after conditioning and filtering from error data. A fault indications and trend correlations will also be seeked.

5.1 Data Mining

To use the data, it must be converted to a matrix based format on a digital environment. To do so, gathered data was transformed to a form of MatLab workspace matrix. As mentioned, the data was stored in two different devices: one for the data of turbine cycles, bearing temperatures and vibration amplitudes; and other for the data of power output in MWs. The first data logger has a logging frequency of 1 data/sec for each data, while power output data was gathered over internet with a variable frequency of approximately 6 seconds for a data.

5.1.1 Data collection & conversion

Gathered data for turbine cycles, bearing temperatures and vibration amplitudes were stored on the data monitoring device with its own format and automatically archived every day. The archive files exported to Microsoft Excel and combined together to form a matrix of 18 columns in order to import the data to MatLab workspace matrix form. The detailed information about the data matrix is on the appendix A.1. The data time interval was selected between the dates 01/12/2008 00:01 – 04/12/2008 00:00. This time interval includes different plant processes and faults together, which creates a better investigation opportunity.

The power output data was also converted to MatLab workspace format from text base logging with the data collection software over internet. The difficulty of this was to log the variable time data accurately with power output. As because of the variable frequency of data gathered, the time stored separately and added to the power output data matrix in MatLab workspace form.

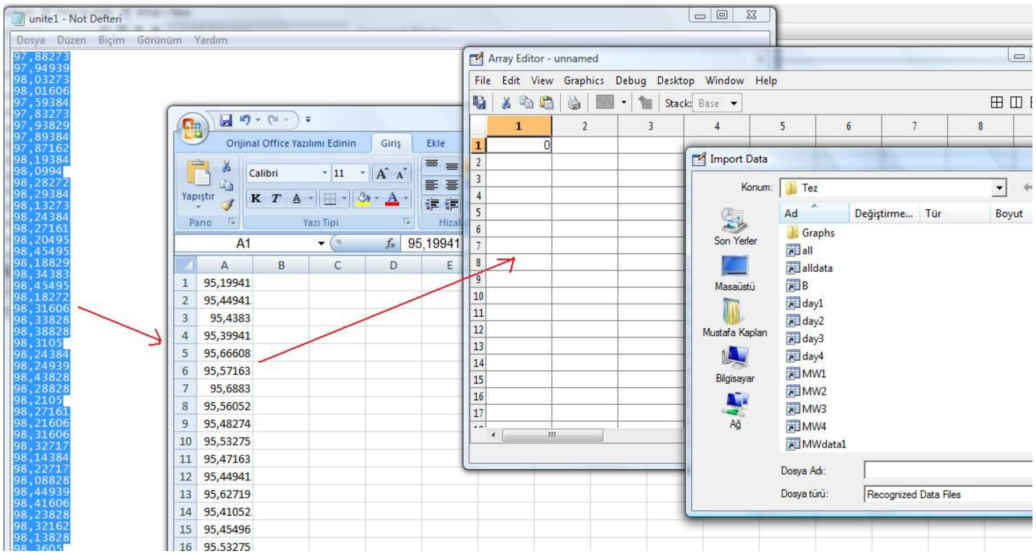


Figure 5. 1 : Collection and conversion of power output data.

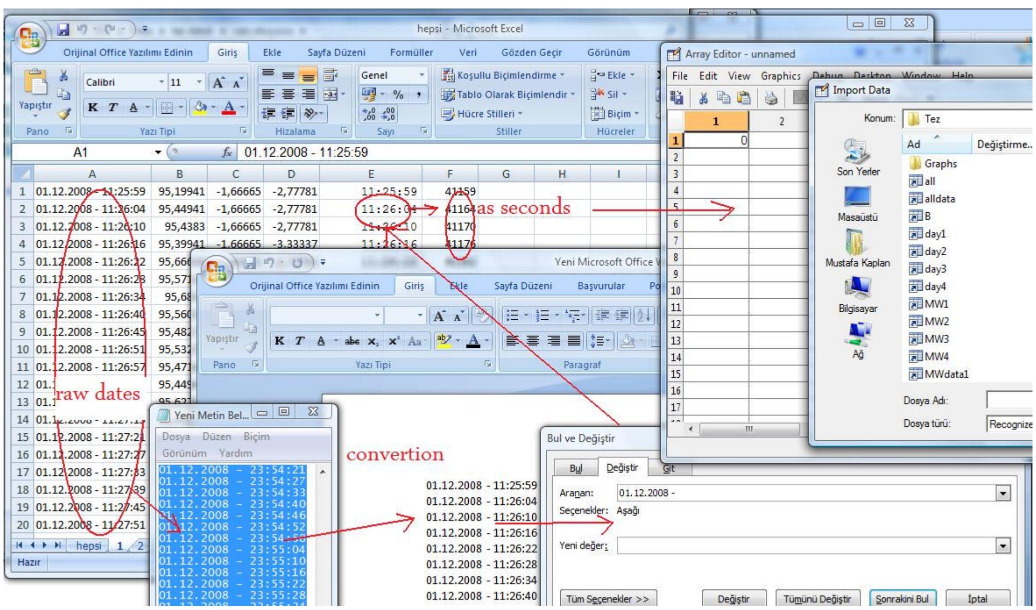


Figure 5. 2 : Collection and conversion of cycles, temparatures and vibrations.

5.1.2 Physical meanings of collected data

In this work, every data collected from the plant is directly about the Turbine&Generator complex. There is also other data which has effects on the system, such as oil pressures etc.; but for simplification, the most important and gatherable data were collected. In addition, to monitor and work on all data will be a very much complex work and not necessary for this stage. This chapter will inform about these collected data, and the information they may carry.

5.1.2.1 Turbine cycles

Turbine Cycles varies around 3000 rpm, which means 50 Hz, the mains(network) voltage frequency. As all online power plants are connected with interconnection to each other, the frequency is kept the same while the power load changes.

The cycles data can give the information of turbine&generator functional stage – whether it is online or not, also the interconnect frequency changes. It is useful before the plant unit is online, and while the unit is starting and connecting to network.

5.1.2.2 Bearing temperature

Main bearing temperature data is taken from the between turbine and generator, thus it is obviously an information about bearing condition / faults which can be caused by oiling problems, high vibration, sudden speed or load changes.

5.1.2.3 Vibration amplitudes

The vibration amplitude data is the integration of the vertical vibration signal over the shaft, and not the wave itself. It is because, the continuous vibration signal itself is both hard to log and useless without processing. That’s why, the vibration amplitude is more useful when it comes to practice in maintaining plant. However; the vibration signal itself could be a very good for fault detection, but this work’s focus is on trend viewing of practical data. The vibration amplitudes are logged to operation papers both by the operators, and monitors, and attached to alarm signals.

In this work, for Units 1 and 2, vibration amplitude data of 2nd , 3rd and 4th bearing points were taken, while a 5th point was added to Unit 3 because of its risk of failure and reported problems about vibration is higher. The 1st bearing points are at the end of the turbines(High Pressure section) and has very low failure risk and low vibration, so it was negated.

Comparison among the vibration points showed that the 4th point is the most critical one – as the expert reports supported, while other vibration characteristics are quite similar to 4th one. For easy trend viewing, the 4th vibration was taken into consideration, while other vibrations only used for critical points of detection and comparison.

The vibration amplitude generally carries information about potential dangerous faults of the turbine&generator complex, which can be caused by sudden changes in load, bearing problems in continuous changes and balance problems; as well, system resonance is always a subject to peak vibration amplitudes.

5.1.2.4 Power output

The main outcome of a power plant is actual power output, thus it is important to track this data. As power output is the outcome, so it can be effected by anything from the plant. However having the data at a low rate, the power output trend can carry a lot of information about both the plant and the electricity network.

5.2 Data Conditioning

The data needs to be conditioned and filtered before it gets ready to be interpreted. At the inspections, some data errors such as discontinuous or disoriented data points appeared. These can be detected easily by viewing the data. These errors are named as outliers and zero or empty values. At the upcoming section these errors will be informed.

In contrast of the outliers and zero points, further data conditioning techniques are not as easy as them. In this work, data de-noising techniques is used according to the mathematical approaches mentioned at chapter 4.

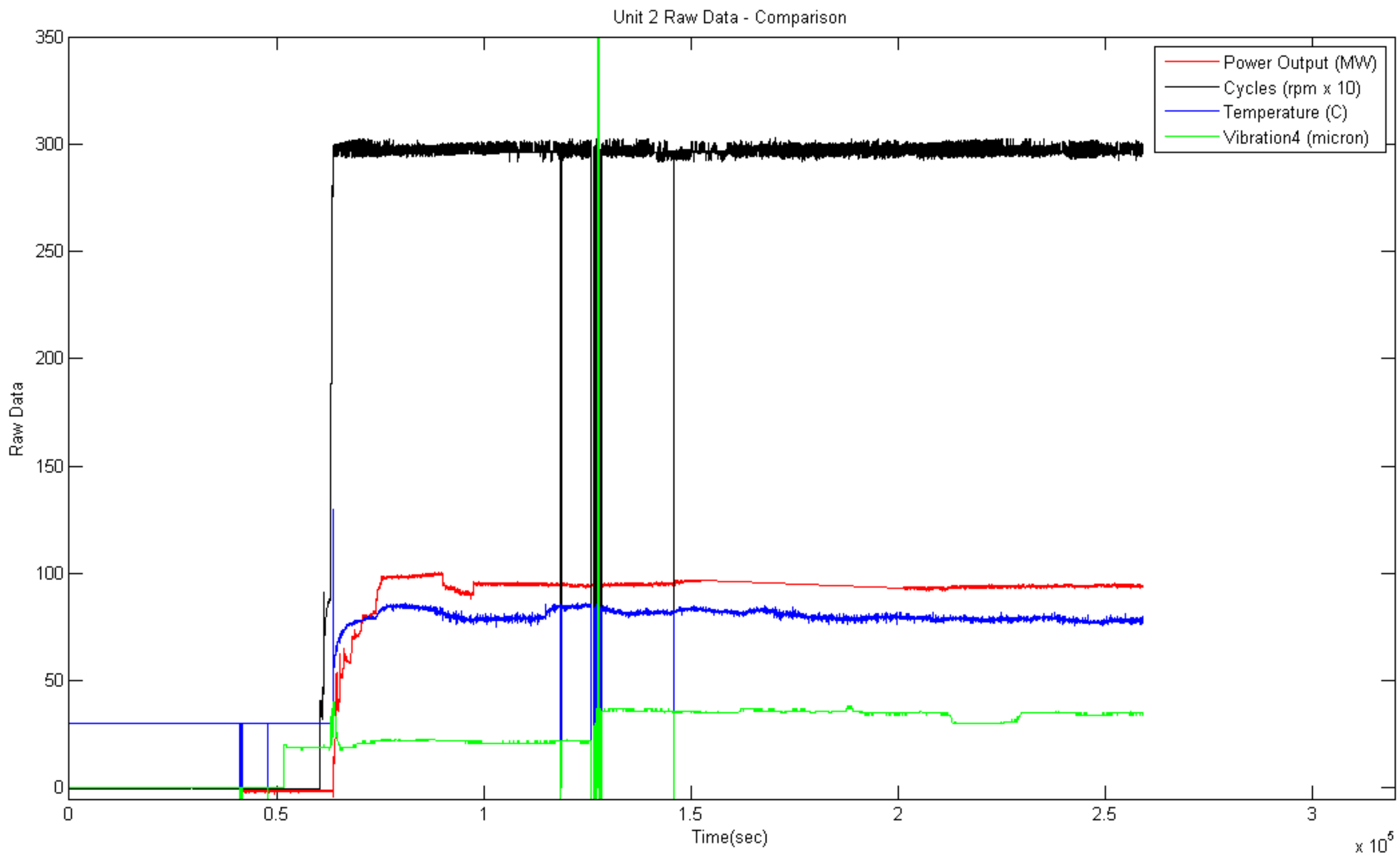


Figure 5. 3 : Unit 2 raw data view.

5.2.1 Data pre-processing: Outliers

Before working with a data / signal, it must be conditioned. And most data carries unsuitable data such as outliers. The outliers are data points that are probably an error. As it is illustrated at chapter 4.2, the outliers and zero points detected and removed.

5.2.1.1 Peak values

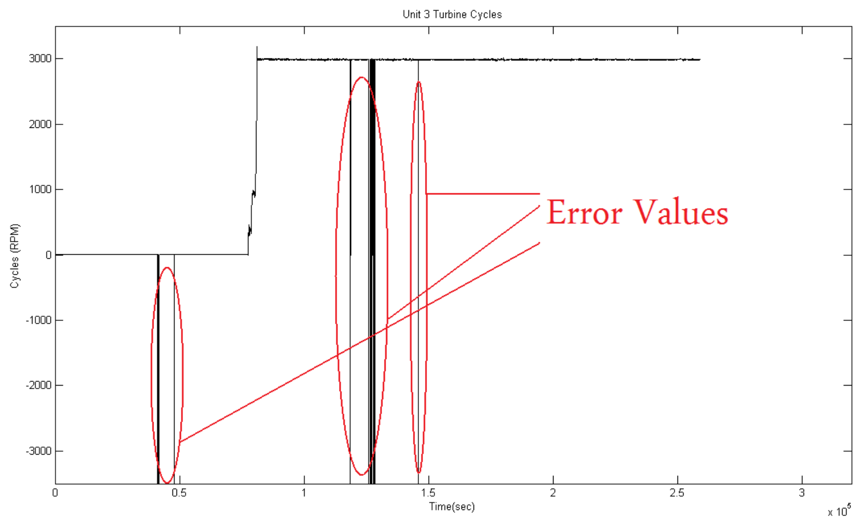


Figure 5. 4 : Peak values.

The data was carrying some very high values, peaks. These were considered as errors. Such as the graph above (figure 5.4), these values are totally unsuitable for the data. In addition, when this measurement is compared with the other measurements at the same time interval, the error values appeared at the same time intervals as seen on the raw data graphic (figure 5.5).

Inspections resulted that, this errors appeared at the time interval when the data logger device is stopped for configuration.

These outlier values were removed from the data as in the chapter 4.2.

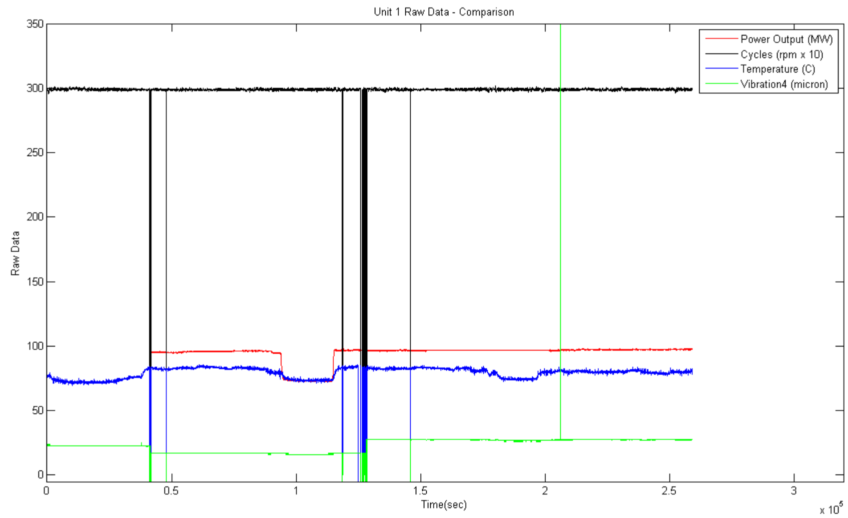


Figure 5. 5 : Unit 1 raw data.

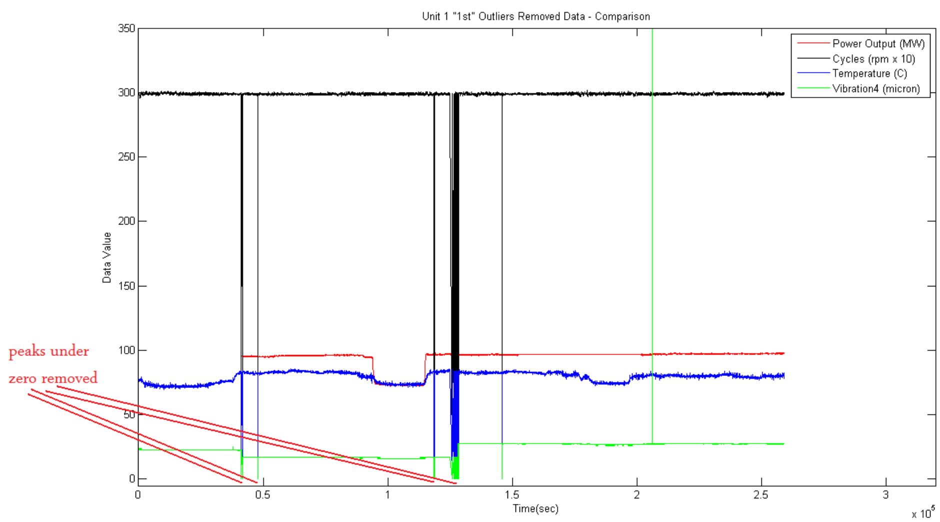
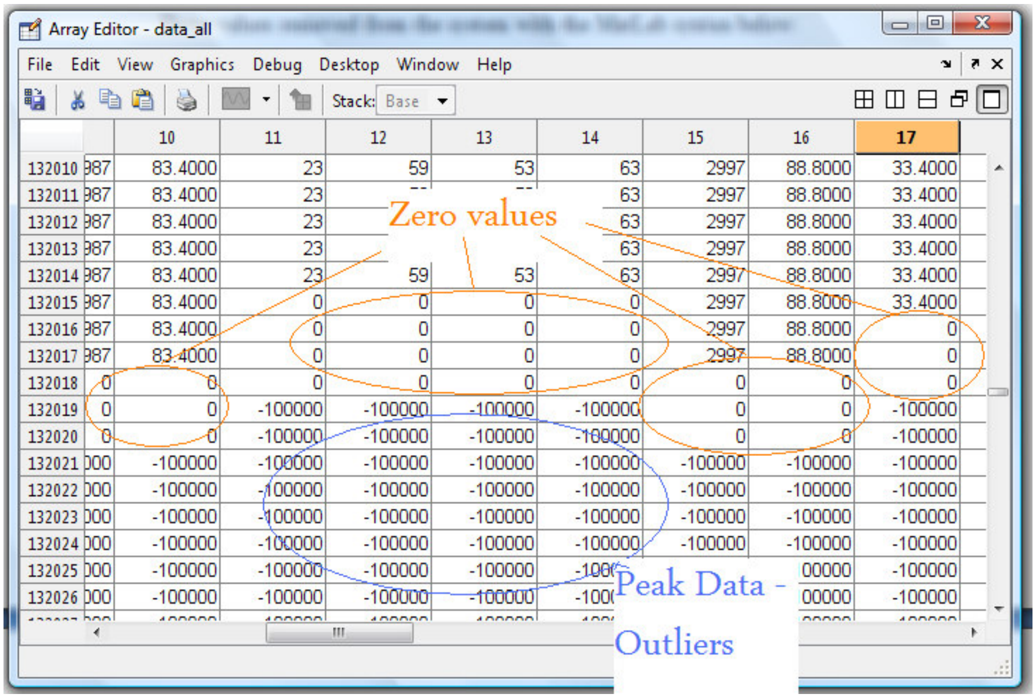


Figure 5. 6 : Unit 1 data after 1st outliers(peaks) removed.

After removing the first outliers, there still are some zero values of great unsuitability.

5.2.1.2 Zero values

After removing the data peaks considered as outliers, there was also remaining unsuitable data left. These data points are empty or zero. However the system has accurate zero data too, there was also some error zero data remained.



		10	11	12	13	14	15	16	17
132010	987	83.4000	23	59	53	63	2997	88.8000	33.4000
132011	987	83.4000	23	[illegible]	[illegible]	63	2997	88.8000	33.4000
132012	987	83.4000	23	[illegible]	[illegible]	63	2997	88.8000	33.4000
132013	987	83.4000	23	[illegible]	[illegible]	63	2997	88.8000	33.4000
132014	987	83.4000	23	59	53	63	2997	88.8000	33.4000
132015	987	83.4000	0	0	0	0	2997	88.8000	33.4000
132016	987	83.4000	0	0	0	0	2997	88.8000	0
132017	987	83.4000	0	0	0	0	2997	88.8000	0
132018	0	0	0	0	0	0	0	0	0
132019	0	0	-100000	-100000	-100000	-100000	0	0	-100000
132020	0	0	-100000	-100000	-100000	-100000	0	0	-100000
132021	000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
132022	000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
132023	000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
132024	000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
132025	000	-100000	-100000	-100000	-100000	[illegible]	[illegible]	00000	-100000
132026	000	-100000	-100000	-100000	-100000	[illegible]	[illegible]	00000	-100000

Figure 5. 7 : Raw data matrix.

Inspections showed that some of the zero data are just before the data considered as outliers. Therefore, as a conclusion, this error is caused by the transient log lock-up before the device is stopped for configuration. It generally lasts for couple of seconds. These data also removed with another outlier algorithm.

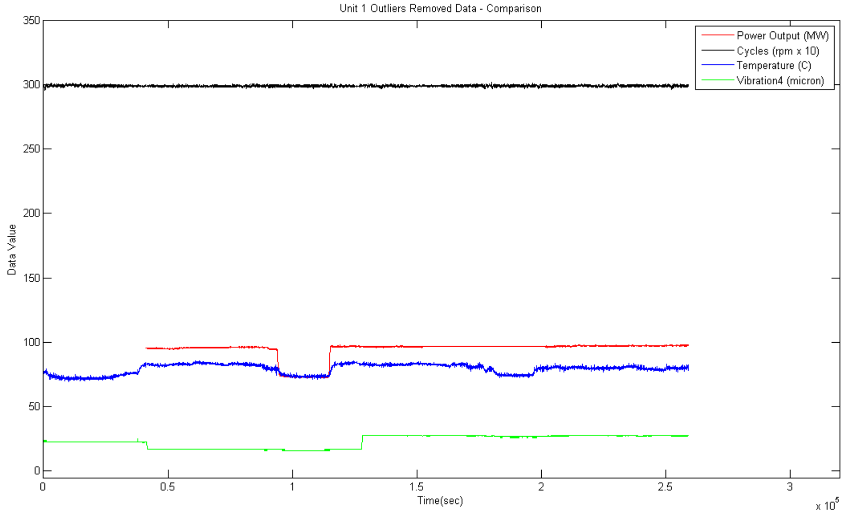


Figure 5. 8 : Unit 1 data after all outliers(peaks and zeros) are removed.

5.2.2 De-noising

Even after the outlier removal, the data contains a lot of noise which makes trend analysis difficult. Most of the noise is because of the sensors, and to have a smooth data, de-noising was needed to be applied.

As in the chapter 4.5, de-noising applied to data. Trial and error technique used and the denoised data compared with raw data to create the suitable data. As different de-noising techniques with several wavelets and different levels are available and some of them were tried, it is ended up with Daubechies' mother wavelet of db40 at a level14.

At the figures 5.9 and 5.10, de-noising effect can be seen for Unit 3. The detailed de-noising comparisons with original data is given in the upcoming chapters.

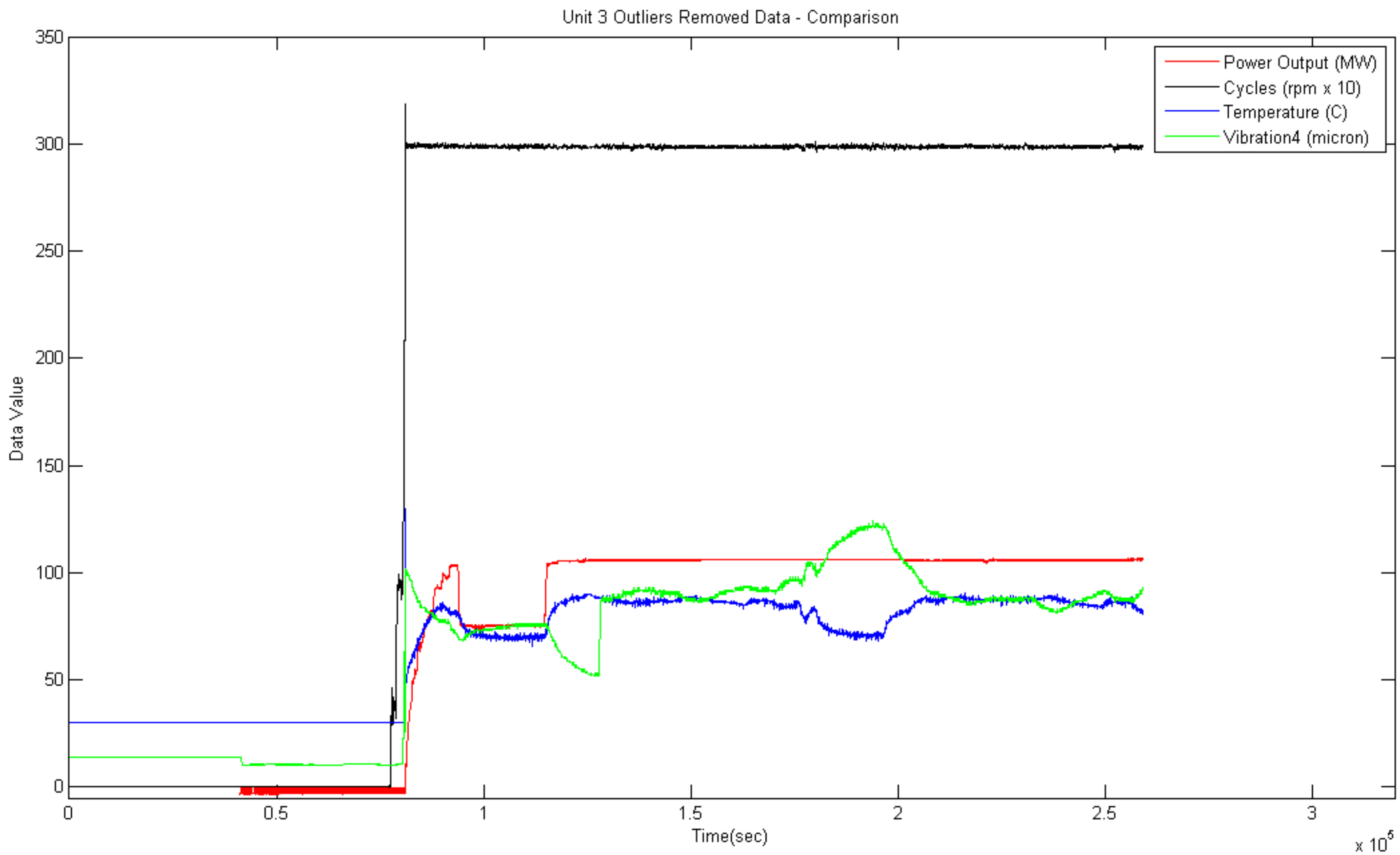


Figure 5. 9 : Unit 3 data after all outliers (peaks and zeros) removed.

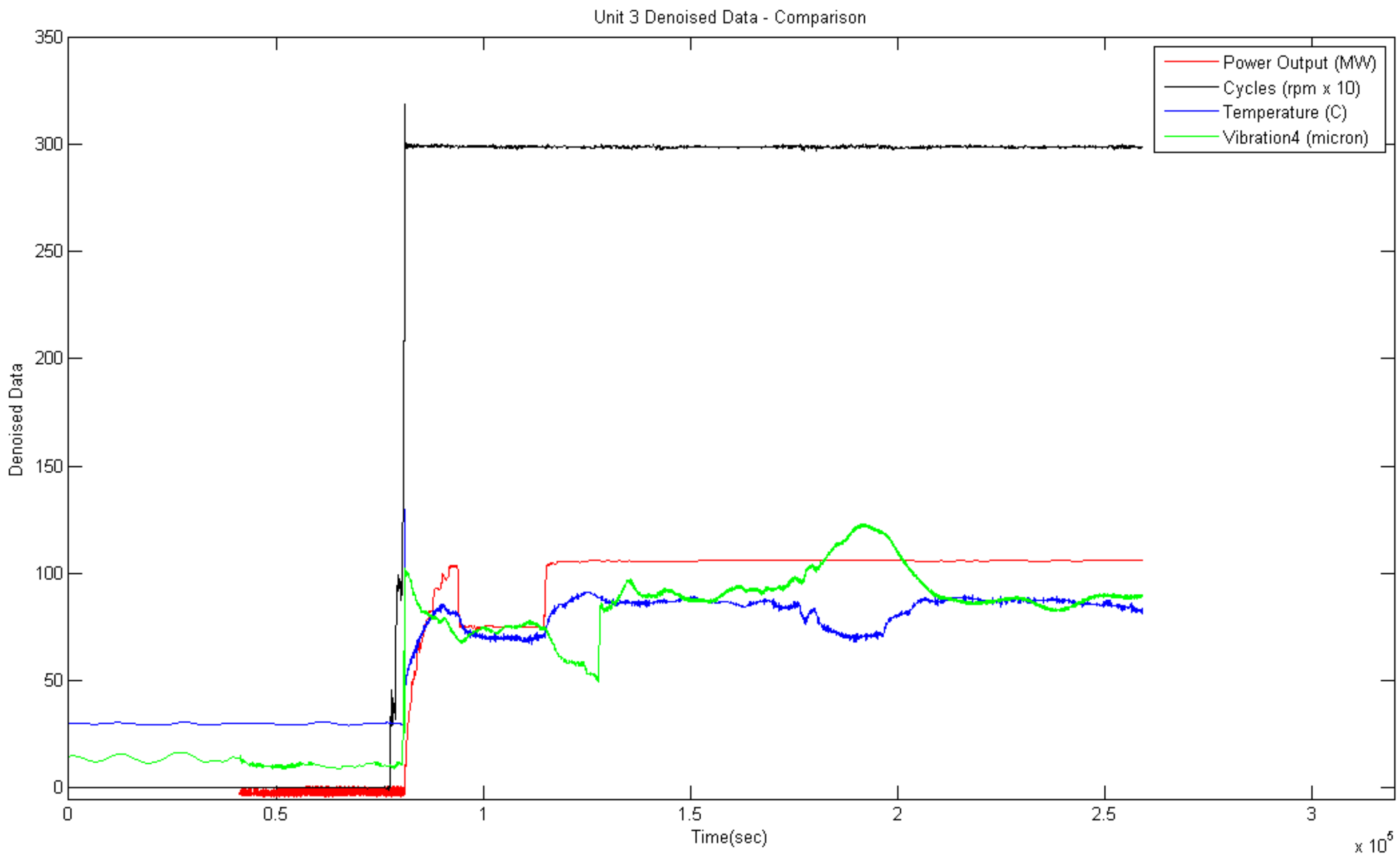


Figure 5. 10 : Unit 3 data after de-noising.

5.2.2.1 De-noised data comparison

To check the effect of de-noising, the figures below prepared for illustration:

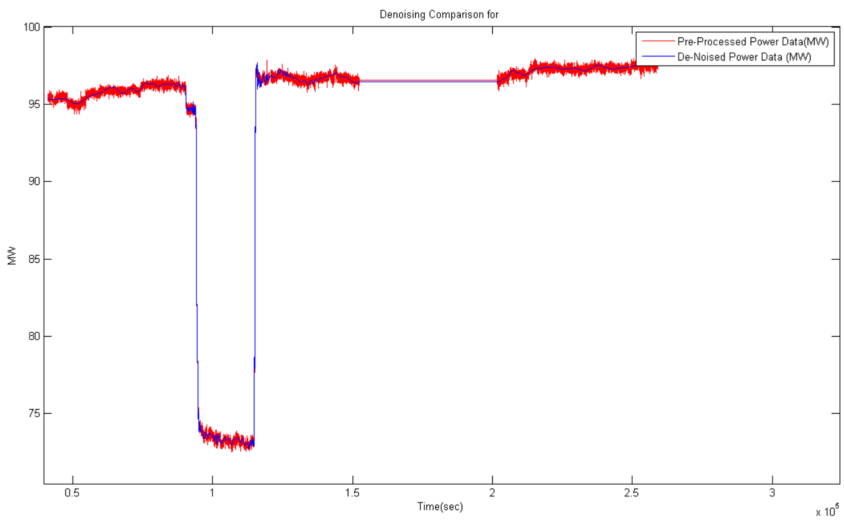


Figure 5. 11 : De-noising comparison: unit 1 power output.

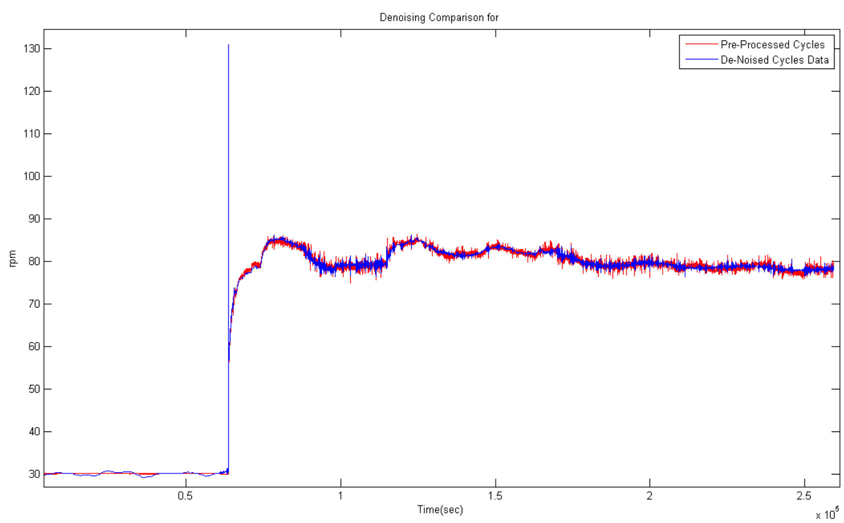


Figure 5. 12 : De-noising comparison: unit 2 temperature output.

These graphs show that a more stable trend data created with the help of de-noising.

5.2.3 Noise characteristics: Statistical parameters of the noise

A Gaussian noise has statistical characteristics of: skewness = 0 , kurtosis = 3 while standard deviation and mean can varies according to data [13].

Statistical parameters are calculated of the noises which are at the table 5.1 below:

Table 5. 1: Statistical parameters of noises

Statistical Parameters for Noise	Mean	Standart Deviation	Skewness	Kurtosis
Unit 1 - Power Output	0,001086505	-0,029177501	0,003120344	-0,001527665
Unit 1 - Turbine Cycles	0,182613484	5,003713193	0,755648708	0,300181252
Unit 1 - Temparature	-0,13784232	-0,140624437	0,007098108	-0,434768379
Unit 1 - Vibration 4	3,446389027	4,177954924	4,154596723	3,929561395
Unit 2 - Power Output	0,074447927	-0,0218972	0,002729001	-0,001591083
Unit 2 - Turbine Cycles	0,454275734	14,47809456	0,491628332	0,560427468
Unit 2 - Temparature	0,120271952	0,231939856	0,085363095	0,098633226
Unit 2 - Vibration 4	3,481991987	3,891428956	3,914106095	3,597656218
Unit 3 - Power Output	-0,00530238	0,004826683	0,016986963	-0,009904431
Unit 3 - Turbine Cycles	0,253440101	3,145934556	0,55294547	1,321456806
Unit 3 - Temparature	-0,048975906	-0,140036845	0,573089554	-0,311447192
Unit 3 - Vibration 4	5,672226154	4,520667539	5,242259148	5,079344048

5.3 Data Trend Analysis

After the processing of the data, some different issues in the trends attracted attention. With the help of inspection on these trend changes, some conclusions were arrived.

Firstly, correlation between data trends for each measurement will be seeked, and after, some faults will be tried to be characterised.

5.3.1 Correlation seeking

5.3.1.1 Insipient vibration change in unit 1

An incipient vibration amplitude change was spotted between the 4 – 13 x 10^4th seconds which is about the middays of 01.12.2008 and 02.12.2008. The change can be seen below:

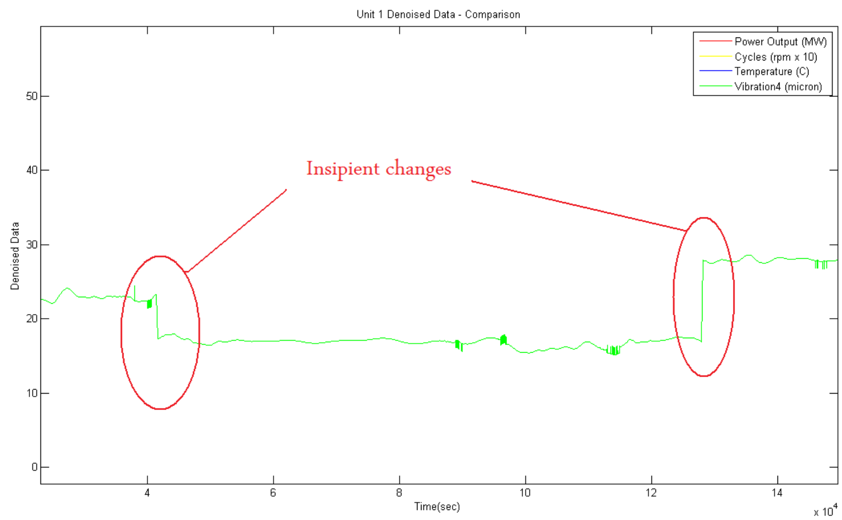


Figure 5. 13 : Incipient vibration amplitude change in unit 1.

Inspections showed that, an operator changed the amplification scale of the data acquisition card of vibration input, and made it appropriate after one day for a test. And the insipient changes had no real system effect.

5.3.1.2 Power change in a correlation between temperature

A power change between the 02.12.2008 hours about 00 – 08 was spotted. There also a correlation between power load to bearing temperature loss, however no formulizable mathematical function can be created. It can be said that, power load may have a direct proportion to bearing temperature.

Inspections showed that, between these times, the electricity distribution center requested a power reduction for the unit and it is a normal operation. No fault indication may be concluded from this trend.

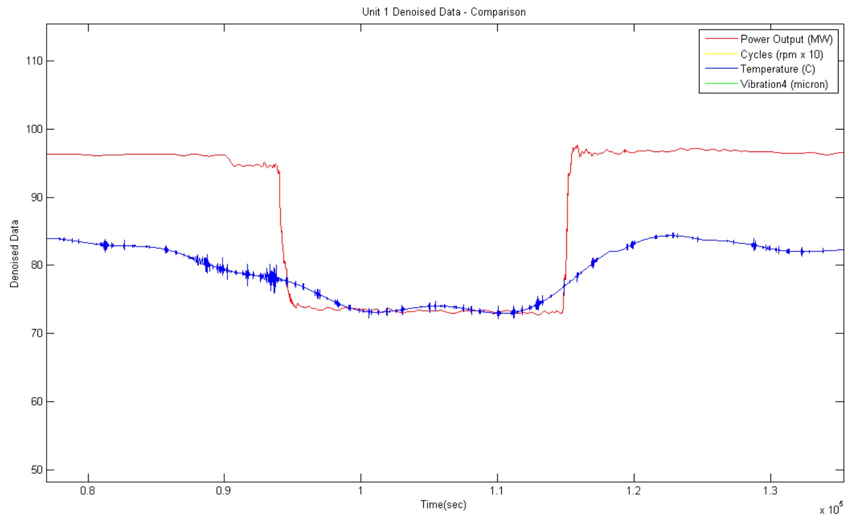


Figure 5. 14 : Power change correlation between temperature - unit 1.

5.3.1.3 Straight power output

At the times between 15 – 21 x 10^4th seconds there is a power stability that may be an error in the power output data. There is also a bearing temperature fall at these times, that can be an indication of a power load reduction.

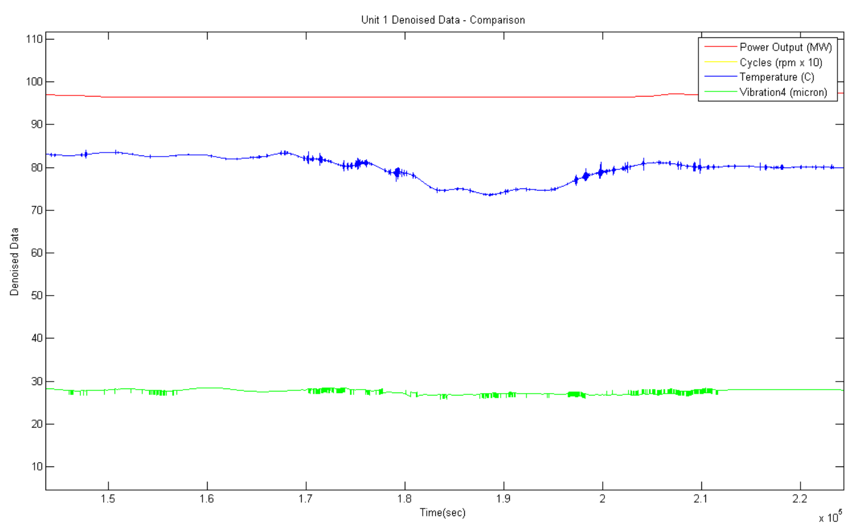


Figure 5. 15 : Straight power output data.

Inspections showed that the software had a problem about logging power data between these times and no power output measurements made at that time interval. Also, it is asked to power distribution central if there is a planned power loss at that time interval and gathered the data below:

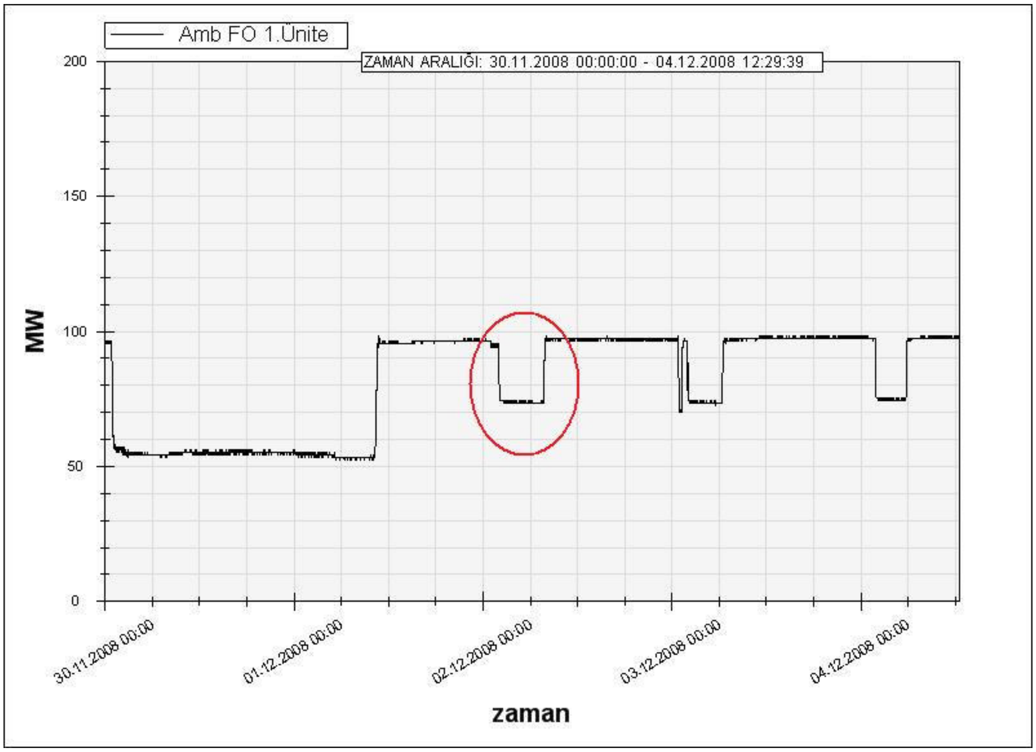


Figure 5. 16 : Unit 1 power output data from power distribution center.

As shown above, between same time interval, there is another power load reduction. This also supports the conclusion at the section 5.3.1.2 about the correlation between power output and bearing temperature.

After the discovery about the problem about the power output logger software, the same problem were seeked in other units and noticed that it exists for all 3 units:

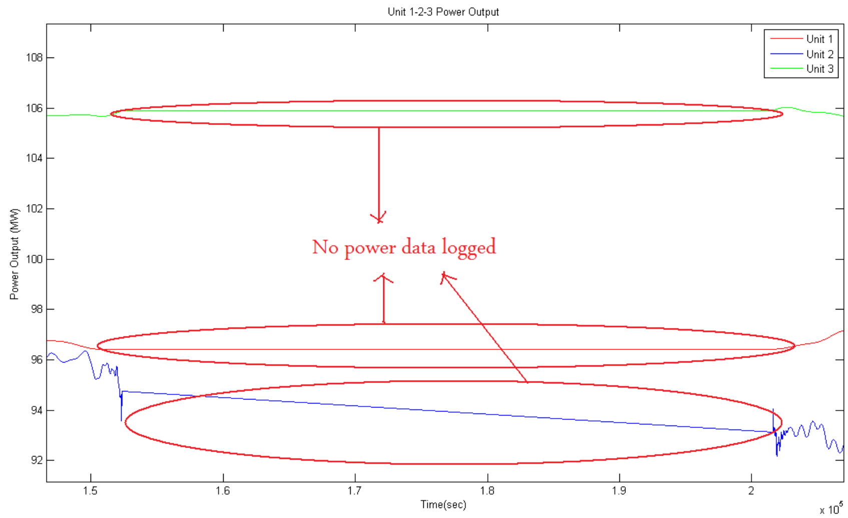


Figure 5. 17 : Power output data loss In 3 units.

5.3.1.4 Unit start-ups.

At the 01.12.2008 hours between 17 and 18 the unit started and became fully powered on-line in the fallowing 3 hours. A unit start-up is great to inspect because there is a lot of changes in these times.

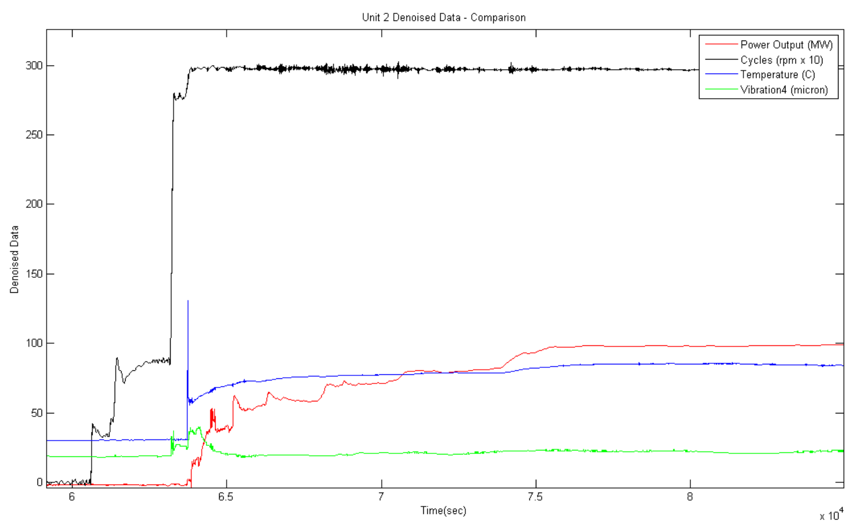


Figure 5. 18 : Unit 2 start-up.

Firstly, the unit has a vibration instability while being on-line, however the fallowing trend of vibration shows us there is a fall after switching on-line.

Secondly, a great bearing temperature peak can be sensed during the unit is being loaded. In addition, the more load the unit takes, the more bearing temperature rise occurs. This last information also powers the conclusion in chapter 5.3.1.2.

To check the trends, Unit 3 start-up was also inspected:

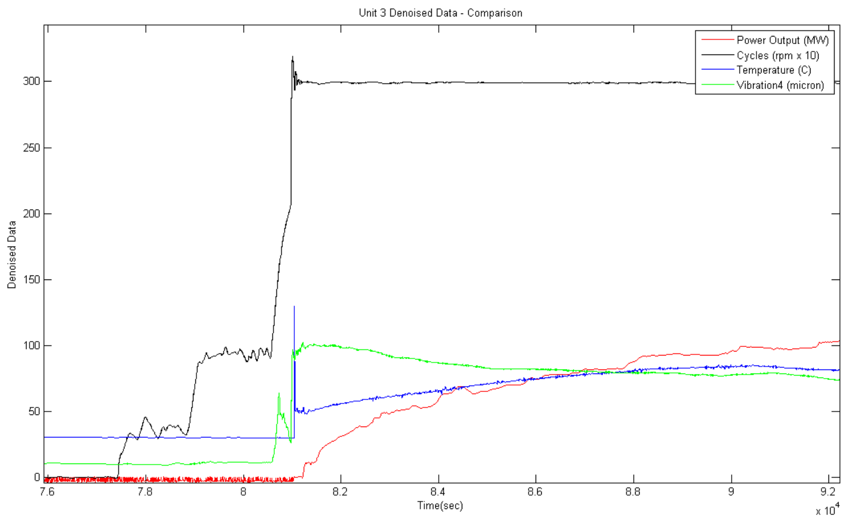


Figure 5. 19 : Unit 3 start-up.

Unit 2 start-up is followed by unit 3 start-up. As shown at figure 5.19, the same vibration instability can be noticed at the start-up. In contrast of unit 2, there is another great rise in vibration at the time of switching on-line. Operators reported a powerful vibration activity in the whole turbine building for unit 3 at the time of being on-line. This could be an indicator of unbalance or another turbine or generator fault. However, the fallowing vibration trend shows the same structure in unit 2 at the time of rising power load.

The temperature trend has the same characteristics as in the unit 2, so most of the findings for start-up trends supported.

Different than the unit 2, unit 3 has an instability of cycles added a peak for about several minutes while being on-line. As inspections showed that, while being on-line, synchronizing the mains frequency with the plant unit can cause these changes.

5.3.1.5 Unit 2 unstable cycles

In contrast of the other two units, unit 2 has a very unstable cycles measure. Altough after data processing, it is seen that a noisy cycles data appears.

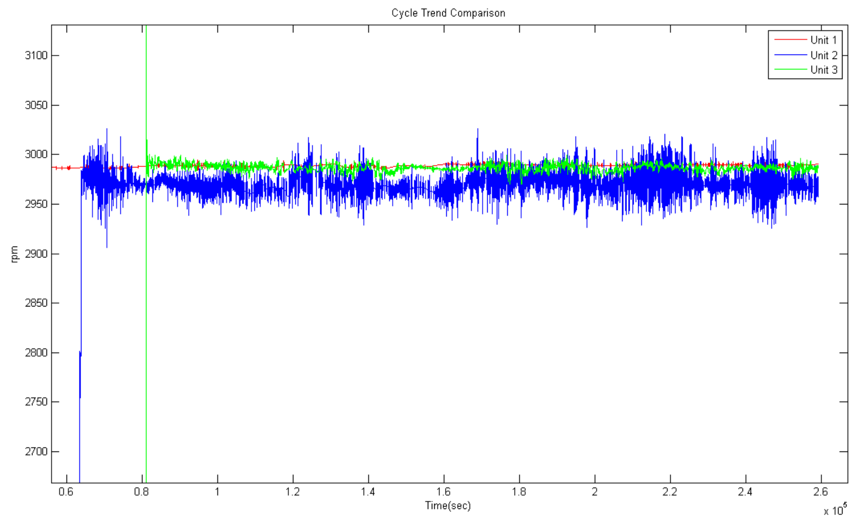


Figure 5. 20 : Cycles comparison between units 1-2-3.

Inspections showed that, cycle sensor of unit 2 have some noise issues and outputs a noisy signal to the data acquisition system. There is no turbine or generator fault related with this. It also can be seen in figure 5.21, there is no correlation with other measurements in unit 2.

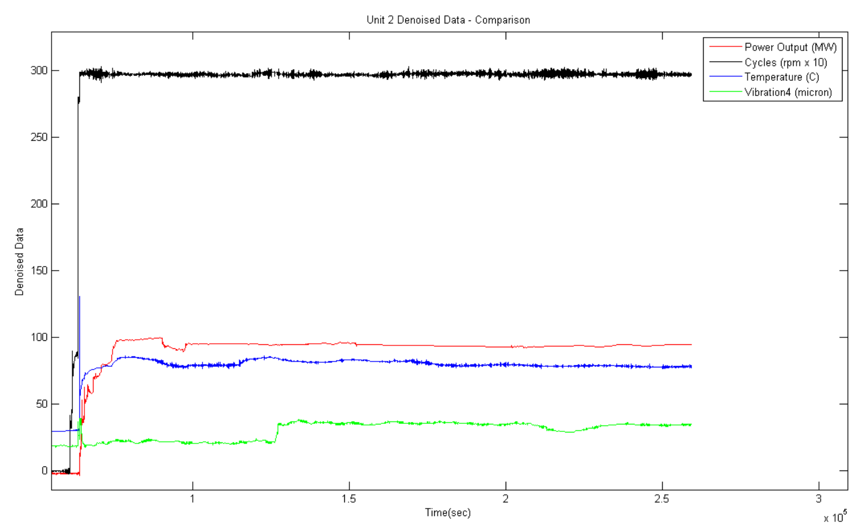


Figure 5. 21 : Data comparison while unit 2 is on-line.

5.3.1.6 Temperature change for unit 2

From about 01.12.2008 23:00 to 02.12.2008 08:40, there was a bearing temperature fall in the unit 2. At the same time interval, there is also a planned power reduction for about 2 hours. It can be seen that at the same time the little about %5 power loss had an effect on bearing temperature as it powers the conclusion in chapter 5.3.1.2, however the total temperature fall for about 9 hours has not a suitable correlation with the other measurements.

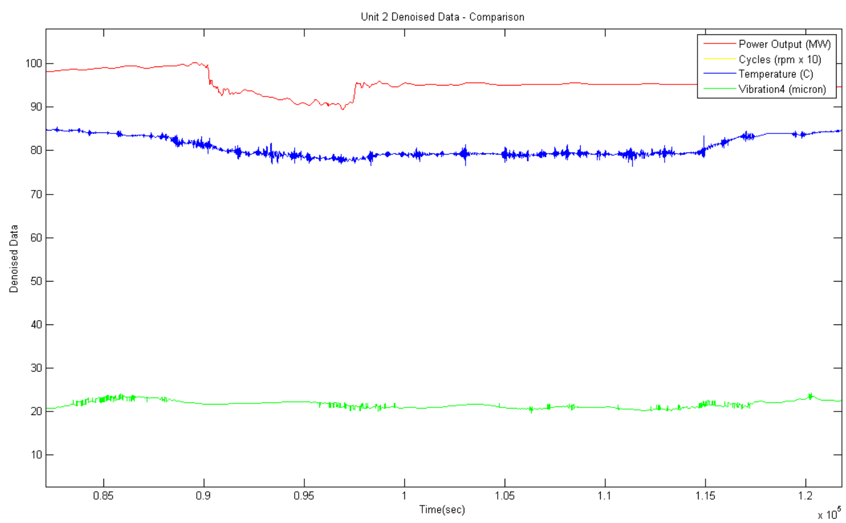


Figure 5. 22 : Temperature change for unit 2.

No exact results could be reached for this temperature loss and only it could be concluded as it might be related with another subsystem parameter change in the turbine&generator complex.

5.3.1.7 Unit 3 power reduction

As it an be seen in the figure 5.23, a 28 MWs power reduction lasting about 6 hours was made in unit 3 at 02.12.2008, 2 a.m. at night. With this power reduction, it is seen that a bearing temperature between this hours existed. Also, a vibration change occurred at this time interval without a direct correlation between power output.

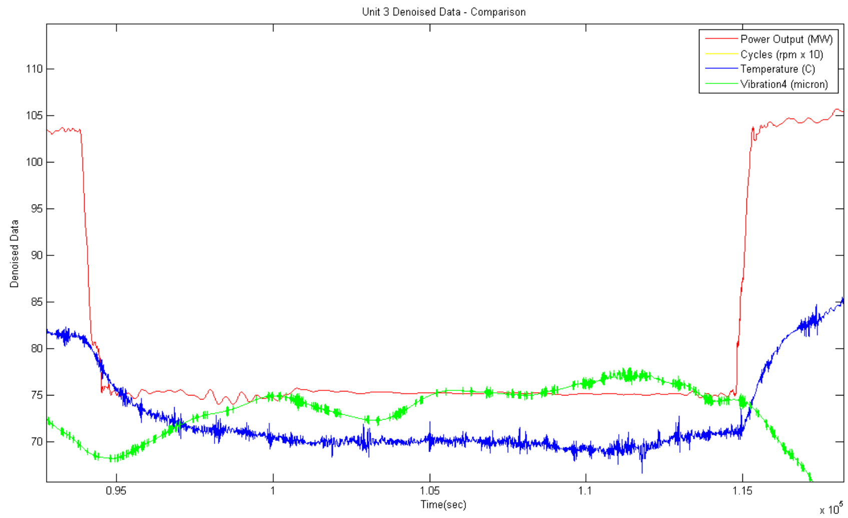


Figure 5. 23 : Unit 3 power reduction.

Inspections showed that the power reduction is a planned one, and it is not an indicator of any faults, and in addition, this power output to bearing temperature correlation supports the conclusion in chapter 5.3.1.2.

5.3.1.8 Unit 3 bearing temperature – vibration amplitude correlation

In figure 5.24, the comparison of bearing temperature and vibration amplitude for unit 3 is shown.

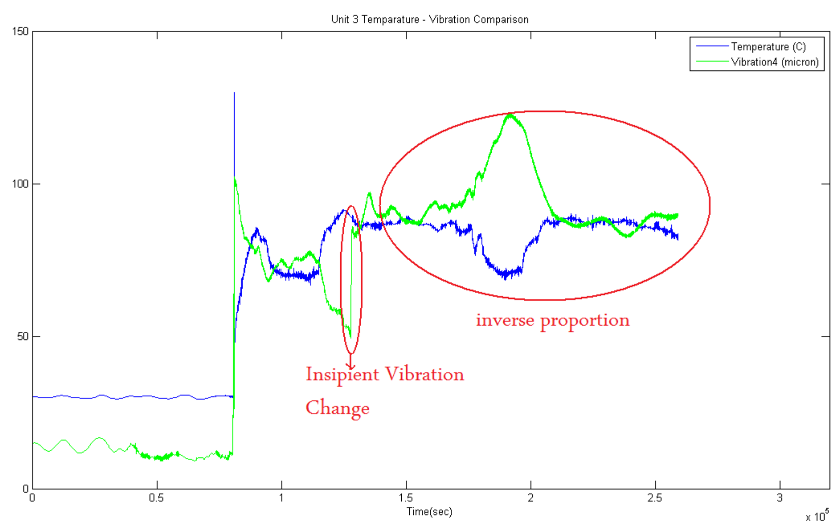


Figure 5. 24 : Unit 3 temperature – vibration comparison.

Firstly, the insipient vibration rise at the 13 x 10^4th second can be detected. As it mentioned in chapter 5.3.1.1 , it is not a physical change in the vibration, and only it is because of a change in the amplification scale of the data acquisition card done by an operator.

Secondly, there is an inverse proportion between the vibration amplitude and bearing temperature. As the vibration data shown in these graphs are from the 4th vibration sensor and the other vibration sensors were ignored, there could be a suspicion on this comparison. At the figure 5.25, all other available vibration measurements compared with the data available.

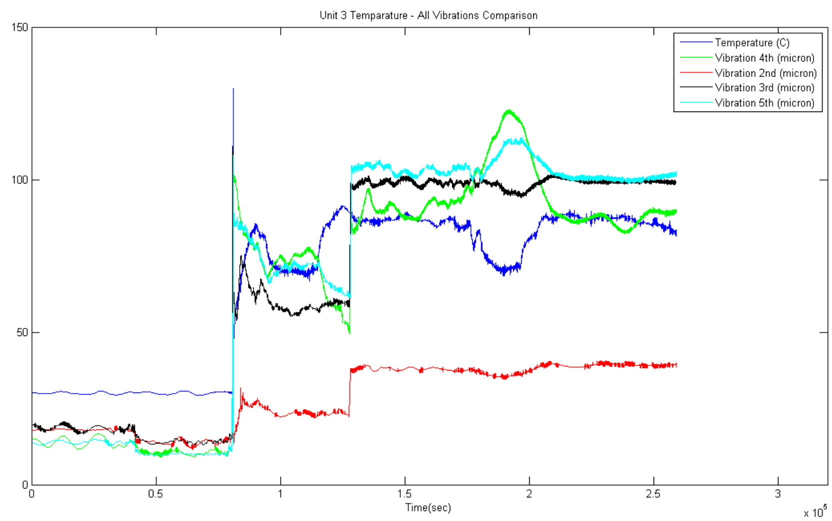


Figure 5. 25 : Unit 3 temperature – all vibrations comparison.

Comparison between all vibrations in unit 3 shows that the 5th sensor also outputs a vibration signal with a similar structure to 4th sensor. Both of the 4th and 5th sensors are located at the generator sides, near the low pressure turbine, and the average values of the vibration amplitudes are risky high. In addition, there are reports from the operators of the plant about high vibrations for unit 3 turbine building, and this can be an indicator of a turbine fault.

In contrast to 4th and 5th sensors, the 2nd and 3rd sensors, which are located near to high pressure sides of the turbine, has a vibration trend more similar to temperature change. Even tough the 3rd sensor has also a high average vibration setting, the 2nd one has acceptable low values. It will be wise to consider the 3rd vibration sensor is more close to low pressure side. To conclude, these vibration levels has a high probability of an indication of low pressure turbine fault and must be furtherly inspected.

5.3.2 Fault seeking

General use of condition monitoring is detecting the faults. To do this, two main inputs needed. Firstly, an enough data about the fault, and secondly a model for fault-data trend change. In this study, the measurements are both less and there is not a fault characteristic model to have reference. Although these boundaries, any trend change can be an indicator of an abnormal state. From this perspective, some probably faults can be seeked from trend changes.

5.3.2.1 Start-ups inspection

At the start-up points, a lot of changes can be observed. As the information about the faults can be gathered from bearing temperatures and vibration amplitudes in this data, a closer look were applied to the start-ups of unit 2 (figure 5.26) and unit 3 (figure 5.27).

There is vibration peaks occurred while the steam flow were being rised to increase the turbine cycles from 800 to 3000 rpm. The first several minutes for increase in steam flow causes high torque resulting a vibration peak while angular acceleration of the turbine is high ($\alpha = \tau / I = \omega / t$).

Inspections showed that, this peaks can be considered as natural in the structure of the turbine&generator complex. However, the vibration amplitude structures are the same for units 2 and 3, the unit 3 has an overall greater vibration levels, thus is an indicator for upcoming faults.

As a conclusion, this inspection ended up with unit 3 has balance problems.

The temperature peaks last about 10 seconds, just after about 15 seconds from the generator became on-line. This gives no indication of faults as well from a view of experts in the plant.

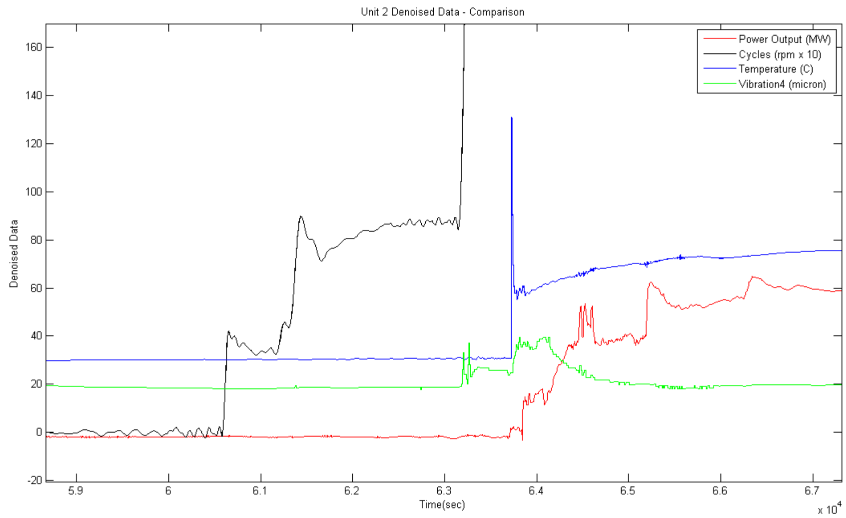


Figure 5. 26 : Closer look on unit 2 start-up.

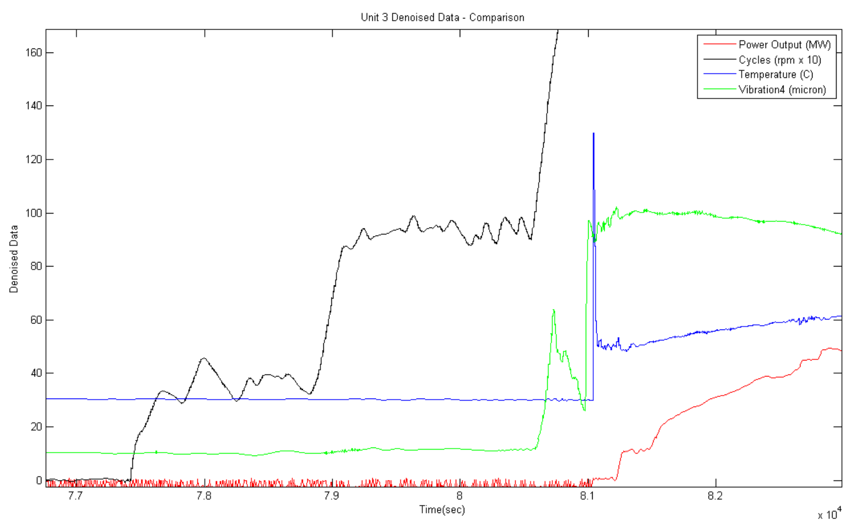


Figure 5. 27 : Closer look on unit 3 start-up resonance.

5.3.2.2 Unit 3 high vibration inspection

As mentioned in chapter 5.3.1.8, there is high vibration amplitude problem in unit 3 which can be seen in figure 5.25.

Inspections showed that the high vibration characteristics of unit 3 is related about the low pressure turbine, which has a high probability of unbalance according to interpretations of experts in the plant.

It was accepted to check the unit 3 low pressure turbine balance in the upcoming planned maintenance

6. CONCLUDING REMARKS AND DISCUSSIONS

As it is mentioned in the first chapter, this work helped to have a practice on data conditioning and analysis on power plants, while developing a data gathering system for a power plant. Furthermore, with the help of trend analysis and expert interpretations, a small conclusion table developed for the real data gathered between 01.12.2008 00:01 to 04.12.2008 00:00.

6.1 Practices

In the second chapter, a brief knowledge was introduced about the thermal power plants. Furthermore, the information was expanded to an active power plant and its components. A lot of information about the subsystems of the plant was inspected while data acquisition and control tools structure was informed in the third chapter.

A great mechatronical and software practice were gained with the help of the data gathering system developed for the plant which includes sensors, data monitors, loggers and software.

Wave and data conditioning methods were included to the study while processing the gathered data, and the methods briefly explained in chapter 4.

Finally, data analysis applied on the processed data of the dates between 01.12.2008 00:01 – 04.12.2008 00:00 and with the help of expert interpretations, physical meanings concluded for trend changes and correlations.

6.2 Trend Analysis Conclusions

As introduced in chapter 5, the inspections showed some conclusions with the help of expert interpretations and inspections in the plant. The conclusions are listed in the table 6.1.

In addition, a conclusion is reached about the noises which are filtered in the chepter 5.2.2. These noises can be concluded as sensor noises due to its statistical characteristics in chapter 5.2.3.

Table 6. 1: Conclusions table

Activity	Conclusion	Type	Chapters
Insipient vibration change between 4 – 13 x 10^4th seconds	change in the amplification scale of the data acquisition card of vibration input by operator	Data Gathering Error	5.3.1.1
Bearing temperature - Power output correlation	Bearing temperature has a direct proportion to power load	Correlation	5.3.1.2/3/7
No power output data logging between 15 – 21 x 10^4th seconds	Power output logger software was shut down for a time	Data Gathering Error	5.3.1.3
Trend changes while unit start-ups	Start-up and connection to network has natural unstable structures - no faults	Natural Response	5.3.1.4 / 5.3.2.1
Unstable cycles measurements for Unit 2	Problem in sensors	Sensor fault	5.3.1.5
Bearing temperature fall between 01.12.2008 23:00 to 02.12.2008 08:40	No conclusions made	Correlation	5.3.1.6
High vibration values for Unit 3	Possible fault for Unit 3	Fault Indication	5.3.1.8 / 5.3.2.2
Vibration Peak while at 800 rpm turbine cycles	High torque input by steam flow causes vibrations to peak	Natural Response	5.3.2.1

6.3 Future Work

This study can be expanded with two different waypoints: first, for to create a model for frequent faults; and second, for a greater scale of monitoring.

Firstly, the trends can be analysed furtherly in a large time interval, while frequent faults can be indexed with the help of operators of the plant. A model for frequent faults to trend changes can be created for developing a smart system to foresee the probable faults.

Secondly, the monitoring and logging system can be expanded into a larger scale to monitor more data at the same time, even on-line. A learning algorithm can be added to the system for whole trend analysis and a large scale fault recognizing system can be seeked.

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APPENDICES

APPENDIX A.1 Data Mining

APPENDIX A.2 Software

APPENDIX A.1

Table A. 1: Stored data in data matrix

Column	Name of the Data
1	Unit 1 : 2nd Bearing Vibration Amplitude
2	Unit 1 : 3rd Bearing Vibration Amplitude
3	Unit 1 : 4th Bearing Vibration Amplitude
4	Unit 1 : Turbine Cycles
5	Unit 1 : Turbine Main Bearing Temparature
6	Unit 2 : 2nd Bearing Vibration Amplitude
7	Unit 2 : 3rd Bearing Vibration Amplitude
8	Unit 2 : 4th Bearing Vibration Amplitude
9	Unit 2 : Turbine Cycles
10	Unit 2 : Turbine Main Bearing Temparature
11	Unit 3 : 2nd Bearing Vibration Amplitude
12	Unit 3 : 3rd Bearing Vibration Amplitude
13	Unit 3 : 4th Bearing Vibration Amplitude
14	Unit 3 : 5th Bearing Vibration Amplitude
15	Unit 3 : Turbine Cycles
16	Unit 3 : Turbine Main Bearing Temparature
17	Ambient Temperature
18	Time in Seconds (from the 01/12/2008 00:00)

APPENDIX A.2 Software

Sorce code for Visual basic of data logger software.

```
VERSION 5.00
Begin VB.Form Form1
  Appearance     =  0  'Flat
  BackColor      =  &H80000004&
  Caption        =  "Veri Okuyucu v1.0"
  ClientHeight   =  1005
  ClientLeft     =  60
  ClientTop      =  345
  ClientWidth    =  5850
  LinkTopic      =  "Form1"
  ScaleHeight    =  1005
  ScaleWidth     =  5850
  StartUpPosition =  3  'Windows Default
  Begin VB.TextBox Text2
    Enabled        =  0   'False
    Height         =  375
    Left           =  1920
    TabIndex       =  2
    Top            =  480
    Width          =  3855
  End
  Begin VB.Timer Timer1
    Interval       =  5000
    Left           =  1440
    Top            =  2280
  End
  Begin VB.TextBox Text1
    Enabled        =  0   'False
    Height         =  375
    Left           =  1920
    TabIndex       =  0
    Top            =  120
    Width          =  3855
  End
  Begin VB.Label Label2
    Caption        =  "Son Güncelleme:"
    BeginProperty Font
      Name           =  "Verdana"
      Size           =  8.25
      Charset        =  162
      Weight         =  700
      Underline      =  0   'False
      Italic         =  0   'False
      Strikethrough  =  0   'False
    EndProperty
    Height         =  495
    Left           =  0
    TabIndex       =  3
    Top            =  600
    Width          =  1815
```

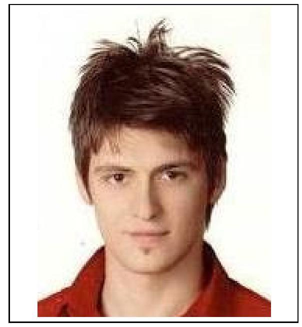
```
  End
  Begin VB.Label Label1
     Appearance      =   0  'Flat
     BackColor       =   &H80000005&
     BackStyle       =   0  'Transparent
     Caption         =   "İçerik Adresi:"
     BeginProperty Font
        Name            =   "Verdana"
        Size            =   8.25
        Charset         =   162
        Weight          =   700
        Underline       =   0   'False
        Italic          =   0   'False
        Strikethrough   =   0   'False
     EndProperty
     ForeColor       =   &H80000008&
     Height          =   375
     Left            =   0
     TabIndex        =   1
     Top             =   200
     Width           =   1515
  End
End
Attribute VB_Name = "Form1"
Attribute VB_GlobalNameSpace = False
Attribute VB_Creatable = False
Attribute VB_PredeclaredId = True
Attribute VB_Exposed = False
Option Explicit
Private Const path = "C:\VeriOkuyucu_v1.0\"
Private Const tempFileName = "temp.txt"
Public xobj As MSXML2.XMLHTTP30

Private Sub Form_Load()
    Text1.Text =
"http://172.17.16.20/pens.asp?UserId=0&Language=0&Device=eZtrend%20QXe"
    'Text1.Text = "http://localhost/winner/main/anasayfa.asp"
    'Text1.Text = "http://www.internethaber.com"
    'Text1.Text = "data.htm"
    DumpFile_V01 Text1.Text
End Sub



Public Sub DumpFile_V01(ByVal FileName As String)
    Dim FileNo As Long
    Dim FileNo1 As Long
    Dim FileNo2 As Long
    Dim FileNo3 As Long
    Dim FileNo4 As Long
    Dim FileNo5 As Long
    Dim LineNo As Long
    Dim LineText As String
    Dim values(5) As String
    Dim PageData As Variant
```

```
'Dim xobj As New XMLHTTP

If Not xobj Is Nothing Then
    Set xobj = Nothing
End If

Set xobj = New MSXML2.XMLHTTP30

xobj.open "POST", FileName & "&rnd=" & Time, False
xobj.send
PageData = xobj.responseText

'Set xobj = Nothing

FileNo = FreeFile ' Get next available file number.

Open path & tempFileName For Output As #FileNo
Print #FileNo, PageData
Close #FileNo

FileNo = FreeFile ' Get next available file number.
'MsgBox "test"
Open path & tempFileName For Input Access Read Shared As #FileNo

Do Until EOF(FileNo) ' Repeat until end of file...
    Line Input #FileNo, LineText ' Read a line from the file.
    LineNo = LineNo + 1
    'Debug.Print Format(LineNo, "00000"); ": "; LineText
    If LineNo = 49 Then
        values(1) = Mid(LineText, 24, 8)
        If InStr(values(1), "<") > 0 Then
            values(1) = Left(values(1), (InStr(values(1), "<") - 1))
        End If
        'Debug.Print Format(LineNo, "00000"); ": "; values(1)
    ElseIf LineNo = 62 Then
        values(2) = Mid(LineText, 24, 8)
        If InStr(values(2), "<") > 0 Then
            values(2) = Left(values(2), (InStr(values(2), "<") - 1))
        End If
        'Debug.Print Format(LineNo, "00000"); ": "; values(2)
    ElseIf LineNo = 75 Then
        values(3) = Mid(LineText, 24, 8)
        If InStr(values(3), "<") > 0 Then
            values(3) = Left(values(3), (InStr(values(3), "<") - 1))
        End If
        'Debug.Print Format(LineNo, "00000"); ": "; values(3)
    ElseIf LineNo = 88 Then
        values(4) = Mid(LineText, 24, 8)
        If InStr(values(4), "<") > 0 Then
            values(4) = Left(values(4), (InStr(values(4), "<") - 1))
        End If
        'Debug.Print Format(LineNo, "00000"); ": "; values(4)
    ElseIf LineNo = 101 Then
        values(5) = Mid(LineText, 24, 8)
        If InStr(values(5), "<") > 0 Then
```

```
            values(5) = Left(values(5), (InStr(values(5), "<") - 1))
          End If
          'Debug.Print Format(LineNo, "00000"); ": "; values(5)
        End If
        DoEvents ' Allow Windows to handle other tasks.
    Loop

    Close #FileNo
    'MsgBox "deneme"
    Kill path & tempFileName

    FileNo = FreeFile ' Get next available file number.
    Open path & "saat.txt" For Append As #FileNo
    Print #FileNo, Date & " - " & Time
    Close #FileNo

    FileNo1 = FreeFile ' Get next available file number.
    Open path & "unite1.txt" For Append As #FileNo1
    Print #FileNo1, values(1)
    Close #FileNo1

    FileNo2 = FreeFile ' Get next available file number.
    Open path & "unite2.txt" For Append As #FileNo2
    Print #FileNo2, values(2)
    Close #FileNo2

    FileNo3 = FreeFile ' Get next available file number.
    Open path & "unite3.txt" For Append As #FileNo3
    Print #FileNo3, values(3)
    Close #FileNo3

    FileNo4 = FreeFile ' Get next available file number.
    Open path & "unite4.txt" For Append As #FileNo4
    Print #FileNo4, values(4)
    Close #FileNo4

    FileNo5 = FreeFile ' Get next available file number.
    Open path & "unite5.txt" For Append As #FileNo5
    Print #FileNo5, values(5)
    Close #FileNo5

    Text2.Text = Date & " - " & Time
End Sub

Private Sub Timer1_Timer()
    Form_Load
End Sub


Public Sub DumpFile_V02(ByVal FileName As String)
    Dim FileNo As Long
    Dim LineNo As Long
    Dim LineText As String
    Dim values(5) As String
```

```
    'xobj.open "GET", FileName, False
    'xobj.send
    'PageData = xobj.responseText



    FileNo = FreeFile ' Get next available file number.

    Open "c:\VeriOkuyucu_v1.0\" & FileName For Input Access Read Shared As #FileNo

    Do Until EOF(FileNo) ' Repeat until end of file...
        Line Input #FileNo, LineText ' Read a line from the file.
        LineNo = LineNo + 1
        Debug.Print Format(LineNo, "00000"); ": "; LineText
        If LineNo = 49 Then
            values(1) = Mid(LineText, 24, 8)
            Debug.Print Format(LineNo, "00000"); ": "; values(1)
        ElseIf LineNo = 62 Then
            values(2) = Mid(LineText, 24, 8)
            Debug.Print Format(LineNo, "00000"); ": "; values(2)
        ElseIf LineNo = 75 Then
            values(3) = Mid(LineText, 24, 8)
            Debug.Print Format(LineNo, "00000"); ": "; values(3)
        ElseIf LineNo = 88 Then
            values(4) = Mid(LineText, 24, 8)
            Debug.Print Format(LineNo, "00000"); ": "; values(4)
        ElseIf LineNo = 101 Then
            values(5) = Mid(LineText, 24, 8)
            Debug.Print Format(LineNo, "00000"); ": "; values(5)
        End If
        DoEvents ' Allow Windows to handle other tasks.
    Loop

    Close #FileNo

    FileNo = FreeFile ' Get next available file number.

    'Open path & outputFileName For Append As #FileNo

    Print #FileNo, Date & " - " & Time
    Print #FileNo, "AMBARLI 1. UNITE  " & values(1)
    Print #FileNo, "AMBARLI 2. UNITE  " & values(2)
    Print #FileNo, "AMBARLI 3. UNITE  " & values(3)
    Print #FileNo, "AMBARLI 4. UNITE  " & values(4)
    Print #FileNo, "AMBARLI 5. UNITE  " & values(5)
    Print #FileNo, "------------------------------"

    Close #FileNo
End Sub


Private Function FunctionReadyStateChange()
    Debug.Print xobj.readyState
End Function
```

```
Private Sub FailedOnReadyState()
On Error GoTo FailedState
   If Not xobj Is Nothing Then Set xobj = Nothing

   Set xobj = New MSXML2.XMLHTTP30

   ' Assign the wrapper class object to onreadystatechange.
   xobj.onreadystatechange = FunctionReadyStateChange

   ' Get some stuff asynchronously.
   xobj.open "GET", Text1.Text, True
   xobj.send

   Exit Sub

FailedState:
   MsgBox Err.Number & ": " & Err.Description

End Sub
```



CURRICULUM VITA

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