Diploma Thesis on the topic

Simulation of the Operational Management of a Wind Turbine Using Matlab/Simulink

Diploma course: Industrial Engineering

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Statutory declaration

I confirm that I have carried out the present work independently and have only used the specified references and resources.

Espelkamp, 15th February 2021.

Armel Ndo

Note of thanks

At this point I would like to thank everyone who has contributed to the success of this work.

First and foremost, I would like to thank my supervisors Prof. Dr. –Ing. Swen Schmeisser and Dr. rer. nat. Sara Kischnick.

Special thanks to my family as well.

1. Introduction

Generating electricity from wind power is one of the fastest growing methods in the world. The kinetic energy of the moving air is converted into electricity by wind turbines that are installed in places where the weather conditions are most favorable.

Wind turbines can be used individually, but are often grouped together to form wind parks also called wind farm. Electricity generated from wind parks can be used to meet local needs or to supply an electricity distribution network for homes and businesses further away.

Energy obtained from the wind can also be converted into hydrogen and used as transport fuel or stored for subsequent electricity generation. The use of this form of energy, reduces the impact of electricity generation on the environment as it does not require fuel and does not produce any pollutants or greenhouse gases.

Wind energy is growing significantly and since 1994 the world market has grown by around 30% per year. The installed capacity worldwide rose from 17,400 up to 650,560 MW between 2000 and the end of 2019. In the European market, which concentrates most of the world's wind farm, Germany remains the leader with almost half of the total capacity. Spain recorded the strongest growth in the last three years with an annual growth rate of 28%. Europe also concentrates industrial and technological activities: Eight European manufacturers are among the top ten in the world, with 70% of devices sold in 2018.
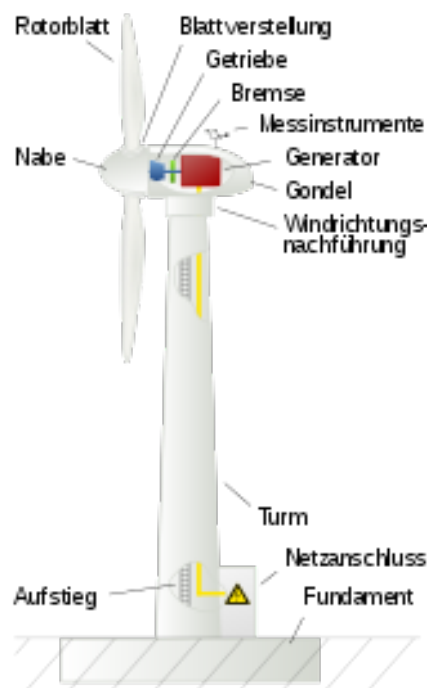

Figure (1.1): Development of power through wind energy; Source: www.wind-energie.de

2. Wind turbine

2.1. The most important components of a wind turbine

Figure (2.1): Scheme of a wind turbine; Source: https://de.wikipedia.org/wiki/Windkraftanlage

Generate electricity using the energy of the wind passes through the installation of a wind generator, and each element of the latter is essential to produce energy in an efficient and safe way.

In practice, the blades of the wind turbine, located at the top of the mast, are powered by the wind. Their movement drives the generator, also placed at the top of the mast. It is that generator that produces electricity (current alternative electric). The mast carries the blades and the generator. The electricity produced is then converted by a regulator with integrated rectifier (which also prevents surges and which can switch to sensors photovoltaic or solar panels in case of under voltage) and routed to the batteries. The energy is thus stored so that it can be returned to needs.

Before being able to use the direct current redistributed by the batteries, it is necessary to however transform it into alternating current thanks to an inverter. Several choices are then available for connection to the electrical network (parallel, temporary or autonomous).

2.1.1   The mast

In order to be efficient, a wind turbine should be able to pick up relatively strong winds. To do this, it is necessary to place it high enough. Thus, the blades and sometimes the generator, are located at the top of a mast whose height varies from 10 to 35 metres. Two types of mast can be distinguished: A classic mast and a pylon.

Classic mast

Figure (2.1.1.1): Representation of a mast; Source: own recording

A classic mast is a vertical rigid element, generally reserved for horizontal wind turbines. Resistant, it must not bend under the wind, and its structure must not be able to be attacked by rust, fungus, mould,…etc. This is why two types of materials are commonly used: Aluminum or a rust resistant metal. During the design, it should be decided whether the mast will be installed on foundations or not: If the generator is located at the top, foundations are essentials. In other cases, they are strongly recommended, as they allow to ensure its good anchoring in the ground. Thus, the wind turbine will not risk being uprooted by the wind. For even greater safety, the mast can be fixed by shrouds, or metal cables that start from the mast and reach the ground. The strength of the mast is then reinforced.

Pylon

A pylon is an assembly of vertical elements, serves to support the wind turbine, whether horizontal or vertical. Just like the mast, it must be fine anchored in the ground to resist winds. Aluminum turns out to be a material of choice for its construction, because it is resistant and does not rust. The negative point of this technique concerns high-rise industrial wind turbines, as the fact that the pylon is not aesthetic, especially when it's high. if opted, a

pylon should be installed on a site clear of all elements liable to be damaged within a radius equal to the height of the wind turbine.

Figure (2.1.1.2): Representation of a pylon; Source: own recording

2.1.2   The generator

Figure (2.1.2): Generator from ENERCON GmbH; Source: https://www.igwindkraft.at

Determinant element of a wind turbine, since it produces electricity, the choice of generator is crucial. A dynamo which produces a direct current, can also be used as a generator. But this solution is not preferred, because transporting a direct current implies large losses. The generator of a wind turbine is an alternator, in other words, it produces an alternating

electric current. Its operating principle relies on setting in motion of a magnetic field created by magnets, thanks to the rotation of blades. So the stronger the magnetic field, the more electricity will be produced.

Two placements are possible depending on the type of wind turbine. For a vertical wind turbine, the generator is most often located at the bottom of the pylon or mast. For a horizontal wind turbine, it is generally installed at the top, directly behind the blades. It is then necessary to convert the alternating current into direct current with a regulator incorporating a rectifier before storing it in batteries. From there the direct current will be converted again in alternating current output, thanks to an inverter, and will be ready to be used in the house.

2.1.3 The gear box

Figure (2.1.3): Gear box for wind turbine; Source https://www.maschinenmarkt.vogel.de

The gearbox also called multiplier transforms the power at low speed and high torque produced by the rotor of the wind turbine, into high speed power and low torque used by the generator. The frequency of rotation is related to the diameter of the rotor and it decreases as the diameter increases. The blades rotate at a relatively slow speed, in the range of 5 to 15 revolutions per minute. The slower they are, the larger the blades are.

Most of the generators need to turn at a certain speed, from 1000 to 2000 revolutions per minute. To keep a good performance it is necessary to increase the frequency of rotation obtained with an engine. That way of increasing the performance is achieved by using a multiplier which is a gear train. In the case of the gearbox of a wind generator, a gear system is generally used consisting of toothed wheels of different diameters with a different

number of teeth. The ratio of the rotational speeds (ω) of the input and output shafts is equal to the ratio of the diameters of the toothed wheels.

The efficiency is variable depending on the power transmitted with an average of 97%. For large, fast-moving wind turbines, the rotational speed is less than 50 revolutions per minute. A speed multiplier with a large ratio is needed (ratio greater than at least 750/50 = 15) except in the case of the use of a synchronous electric generator with permanent magnet and large diameter where the multiplier is reduced or removed, thus offering the advantage of avoiding this efficiency and reducing the weight of the nacelle.

The gear box is a heavy and expensive component but it allows to have a rotor connecting a slow shaft to a slowly rotating multiplier (30 to 40 revolutions per minute) and to be coupled to an inexpensive generator. The gear box also allows a rotor which turns 40 to 50 times faster, to be connected to a multiplier by a fast shaft.

In cold countries, gearboxes must be warmed up. Lubrication of the multiplier can be done by splashing or by forced oil injection. Since gears and bearings are sensitive to particles and moisture, it is necessary to add an oil filter to continuously remove water, wear particles and oxidation products.

The multiplier is mounted on elastic pads (rubber pads) to damp vibrations and limit the transmission of vibrations to the supporting structure. It can also be "floating" to withstand torque surges.

The multipliers operate non-stop and are subject to heavy and variable loads causing wear, which requires preventive and corrective maintenance. Like bearings, industrial gears and axles are designed for a limited life.

The maintenance include the following points:
- Changing oil
- Endoscopic inspection
- Checking the teeth of the gears
- Checking of bearings and almost systematic exchange
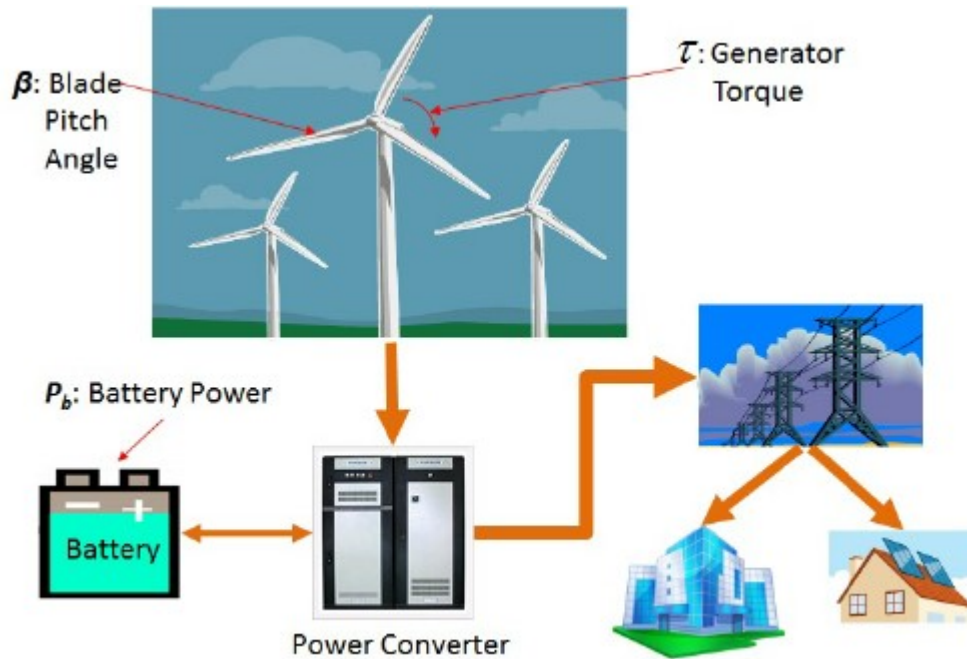- Axis check
- Crankcase check

2.1.4   The battery

Figure (2.1.4): Integrated battery; Source: Publication [1]

The role of the battery is to store the electricity produced by the wind turbine, then to redistribute it as needed. The battery thus serves as a buffer stock between the wind turbine and the electrical circuit of the house, and provides a current constant at exit despite wind variations. Batteries can only store direct current. However a wind turbine produces an alternating current, except in very rare cases where the generator chosen is not an alternator, but a dynamo. The current must therefore be converted via a rectifier. At the same time, to protect batteries against wind variations, a regulator is also essential. The best choice is therefore to opt for a regulator incorporating a rectifier. It then plays several roles: It transforms the current alternating to direct current so that it can be stored in the batteries, and it protects the batteries by injecting a constant charge.

In addition, if the wind turbine produces too much current, the regulator will prevent overvoltage in the batteries by regulating the intake. On the contrary, if the intake is too low, it will interrupt the charge, or even compensate the lack if it is connected to a photovoltaic solar panel (it must then have a photovoltaic input). Still with the aim of protecting the batteries, the regulator also avoids an overload by cutting the supply when they are loaded. Conversely, when they are about to be completely discharged, it supplies the batteries to prevent them from being completely empty.

Constant charged batteries and deep charged batteries are the two options in term of industrial wind turbines. Constant charged batteries are created to deliver a maximum of electricity in a short period of time, but the main problem is that they are quickly discharged. In order not to create any irreversible damage, this type of battery must not be discharged by more than 2 to 5%. In other words, they must be recharged continuously, as the charging and discharging phases cause significant damage. In fact, this solution is strongly not recommended for an Industrial wind turbine, because its lifespan rarely exceeds three

months. Deep charged batteries (lead or gel) are the most suitable for a private wind turbine, because they support perfectly the multiplication of charge and discharge cycles. Lead-acid batteries are less expensive, but discharge if they are not used and they can also induce risk of gas emissions or acid leaks. The more expensive gel batteries are more waterproof and present very little risk of acid leakage. In addition, their composition does not create any danger of gas emissions. Finally, they are as efficient in slow as in fast charging, and the unloading is faster.

2.1.5. The inverter

Figure (2.1.5): Inverter, ABB GmbH; Source: https://www.braun-windturbinen.com/products/wind-inverter/

Before being used, the direct current distributed by the batteries must be transformed into usable alternating current (220 V) thanks to an inverter. Thicker and suitable cables are then necessary, in order to withstand overheating due to direct current.

Part of the Industrial wind turbine and placed between the batteries and the power grid, the inverter has the function of converting the direct current stored and distributed by the batteries into alternating current. This step is essential because the power supply of a house operates on alternating current. Also the inverter makes a noise due to the presence of a fan. For a domestic wind turbine, the inverter models range from 75 W to 10 kW. It is then advisable to choose a power little higher than the needs and not to overload it. For example, a 750 W inverter is ideal for a consumption of 500 W. Be careful however of overheating: The normal power of use, as well as the peak power are mentioned on the packaging and the user should be careful not to exceed them.

On the other hand, an inverter consumes electricity not only in use, but also when it is on standby. Finally, the cables connecting the batteries to the inverter must withstand direct current. For the risk of overheating, it is necessary to use thicker cables suitable for the number of carried amperes.

2.1.6 The blades

Figure (2.1.6.1): Representation of blades; Source: own recording

The blades of the wind turbine are attached to the top of the mast, whether it is a vertical or horizontal model. Driven by the wind, their movement activates a generator which thus produces electricity. The blades of a wind turbine must offer performance, in order to capture as much wind as possible, and safety so that it remains firmly attached with no risk of falling. Every details matter, from size to number including fixing. The blades must therefore combine several qualities: Aerodynamics, lightness and balance.

When it comes to wind turbine blades with vertical axis, there are many possibilities. Savonius wind turbine is the easiest to make and consist of two half-cylinders fixed in staggered rows one in front of the other, or two similar opposing profiles that create a wave shape: The wind rushes in and produces the rotation. This type of blade is most often used for pumping water, as its limited speed still poses performance problems in electricity production today. However, it works with very light winds and offers good resistance to high winds. Darrieus wind turbine is more efficient, but also more complicated to make. They are vertical plates with an aerodynamic profile and which turn thanks to the wind. As for the blades of a horizontal axis wind turbine, they must capture the air, and thus turn to put the generator in motion. For this, the models are most often modeled on the wings of an

airplane. An angle of attack is carefully made at the ends: Between 3 and 6 ° at the end, and between 16 and 25 ° at the start. Of course, these numbers vary depending on the model and the force of the wind. It is also possible to opt for blades with flat shapes, made of light wooden planks or thin aluminum sheets, with an attack angle of 18 °. This solution, although much simpler to implement since it does not involve sculpting the blades, is also less efficient. By the way, most often, an industrial wind turbine consists of three blades, but it all depends on climatic conditions. In fact, the fewer blades there are, the faster the wind turbine will turn. On the other hand, the more there are, the more the wind turbine will be able to pick up weak winds. Already mentioned, the wind turbine blades must be securely fixed to avoid any fall or vibration.

Most wind turbine blades are made of composite materials. The construction of very large wind turbines in particular those for offshore wind farms, are pushing researchers to design increasingly efficient materials. Two words are enough to qualify the materials necessary for the construction of wind turbine blades: Lightness and strength. And the longer a blade is, the more resistant the materials necessary for its manufacture must be.

The materials chosen to build the blades for offshore wind turbines must also be resistant to corrosion. The composite materials used in the manufacture of the blades are blend of fiberglass, carbon fiber, polyester resins or epoxy resins.

Research efforts are now focused on the development of increasingly light and resistant materials. The lightness and strength of these new materials make it possible to manufacture longer blades, to produce more electricity. For example, researchers at the American University of Case Western have developed a composite material made of polyurethane reinforced with carbon nanotubes. Blades constructed from this material are advertised as being eight times stronger than traditional composite blades, while being lighter.
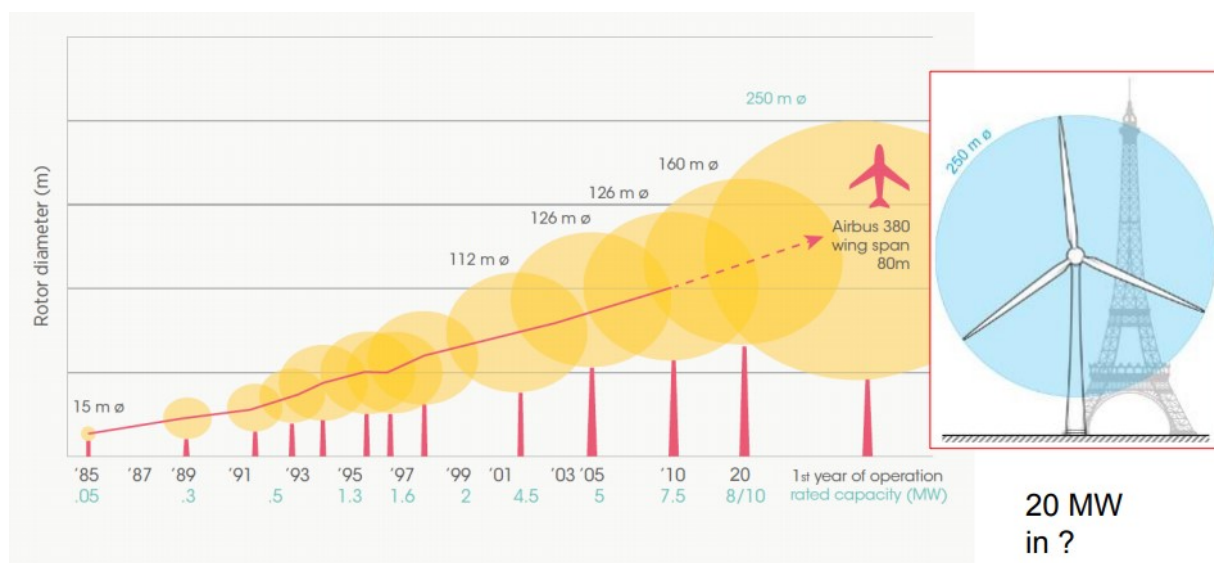

Figure (2.1.6.2): Growth in the size of blades; Source: UpWind 2011

2.2. Types of wind turbines

2.2.1. Horizontal axis wind turbine

This type of wind turbine is the most widespread. It uses the lifting force of the wind applied to the blades, like the wings of an airplane, to power an electric generator or a pump.

Figure (2.2.1): Representation of blades; Source: own recording

2.2.2. Vertical axis wind turbine

- **Savonius type**

Made up of half-cylinders connected to a vertical axis, this type of wind turbine uses the drag force of the wind, on the principle of windmills. Its efficiency is lower than the one for wind turbines which use the lift force, but this type of machine makes it possible to exploit lower wind speeds.

Small in size and quieter than other wind turbines, Savonius wind turbines are ideal for integration into an urban environment.

Figure (2.2.2.1): Savonius wind turbine in Tokyo, Japan; Source: https://de.wikipedia.org/wiki/Savonius-Rotor

- **Darrieus type**

With vertical, parabolic or helical blades, Darrieus wind turbines use the lifting force of the wind, like conventional wind turbines. However, their smaller footprint is an advantage in terms of landscape and architectural integration.

Figure (2.2.2.2): Darrieus turbine (classic) in Germany; Source: https://de.wikipedia.org/wiki/Darrieus-Rotor

Figure (2.2.2.3): Darrieus turbine in the USA; Source: https://en.wikipedia.org/wiki/Darrieus_wind_turbine

- **Quick overview of the types of wind turbines**

own representation	Type	Advantages	Disadvantages
	Horizontal	Yield economic (99% of the market)	- Less resistant to strong winds - Engine brakes - Generator in the nacelle - Orientation in the wind direction
	Darrieus	- Withstands strong winds (220km / h!) - Silent - Ground level generator - Reduced surface	- Low yield - Difficult start - Additional cost of manufacturing the blades
	Savonius	- Works with light wind - Ground level generator - Silent	- Very low efficiency - Sinusoidal torque - Rotor mass

2.3. Offshore wind turbine

Wind power at sea makes it possible to use strong and regular sea winds to produce renewable energy without CO_2 (carbon dioxide) emissions, and has effectively contributed to the diversification of the European energy. Located several kilometers from the coast, offshore wind parks generally consist of several dozen wind turbines which have the particularity of being more powerful than the models used on land.

The primary objective of any designer of floating offshore equipment is to provide the greatest possible stability to their product. When a floating platform undergoes oscillations due to a swell, it exerts a traction followed by a relaxation on the anchoring devices and on the components which connect it to the mainland (pipes or electric cables). Such alternation causes materials fatigue, which degrades much more rapidly than supporting a constant force (permanent traction or compression).

Materials fatigue in the case of floating wind turbines, increases due to vibrations linked to the rotation of the blades. These vibrations occur as soon as the axis of rotation comes out of a strict alignment with the direction of the wind. They can be observed on all wind turbines, including the ones on land during turbulent winds. In the case of a floating wind turbines, in addition to wind fluctuations, any movements of the float can cause a pivoting around the vertical axis including a rocking back and forth or from port to starboard.

Two technologies now make it possible to harness the energy of the wind at sea:
Landed offshore wind turbines are the most common. These are wind turbines whose foundations are installed on the seabed. This technology can be installed in shallow or moderately deep water (5 to 40 meters deep).

Floating offshore wind is an emerging solution. These are wind turbines resting on floats anchored to the seabed by cables. This technology is developed to set up wind parks in deep areas. A pilot project was developed in the Mediterranean: Provence Grand Large located in France.

Figure (2.3): Offshore wind farm in the north sea; Source: https://en.wikipedia.org/wiki/Offshore_wind_power

2.4   Investment costs of a wind turbine

When we talk about the price of a wind turbine, it is important to differentiate the price of a domestic wind turbine, totally adapted to the individual, from the cost of an industrial wind turbine, such as those seen on roads in Germany.

The domestic wind turbine, or small wind turbine, is ideal for domestic use. It is capable of producing enough energy to supply a household with electricity. It is an efficient solution for supplying isolated buildings with electricity.

Industrial wind turbines, also known as large wind turbines or giant wind turbines, are mainly used to generate energy for resale. Its installation is therefore an interesting investment. This type of equipment can reach a height of over 150 metres and is held on the ground by a concrete base measuring 15 to 20 metres in diameter.

Domestic and industrial wind turbines are obviously offered at different prices. Logically, the price of a giant wind turbine is higher than the one of a small wind turbine.

Regarding the cost of installing a wind turbine, it may varies depending on the following points:

- The type of installation to be carried out: On the roof, on an isolated mast, on land, at sea.
- The work to be done: Earthworks, laying, connection, installation of a solar panel in addition.
- Use of the wind turbine: Connection to the network or battery storage.
- The installer price: It varies from one professional to another and depending on the geographical area of intervention.

The following table gives roughly the cost of these two types of wind turbines as an indication to essentially get an idea on how much are they worth it.

Type of wind turbines	Budget
Domestic wind turbine (on mast):	Between 10,000 and 55,000 € (installation and supply)
Industrial wind turbine (onshore farm):	Between 1,4 and 1,6 million Euros per MW (installation and supply)

3.   Matlab / Simulink

3.1.   Matlab

Matlab is a digital calculation software marketed by the company MathWorks. It was originally developed in the late 1970s by Cleve Moler, professor of mathematics at University of New Mexico and then Stanford, to allow students to work from a high-level programming tool and without learning Fortran or C.

Matlab stands for **Mat**rix **lab**oratory. It is a language for scientific computing, data analysis, visualization and algorithm development. Its interface offers, on the one hand, a window interactive console style for command execution, and on the other hand, an integrated development environment (IDE) for programming applications.

Matlab finds its applications in many disciplines. It is a digital powerful tool for modeling physical systems, simulating mathematical models, designing and validating (simulation testing and experimentation) of applications. Basic software can be supplemented with multiple toolboxes. These are libraries of functions dedicated to particular domains. We can cite for example: Automation, signal processing, statistical analysis, optimization, ...etc.

When starting Matlab, the following interface appears:
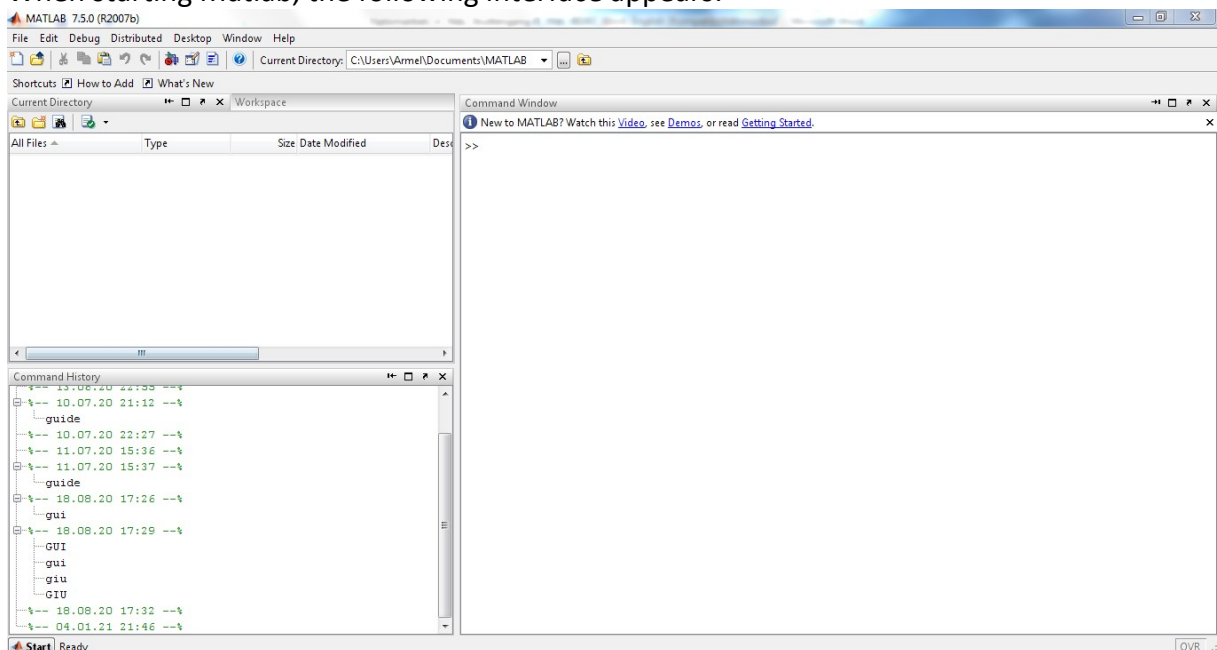
Figure (3.1): Matlab's Interface ; Source: own installed software (Matlab R2007b)

The software offers a real working environment made up of multiple windows. We can distinguish four blocks:
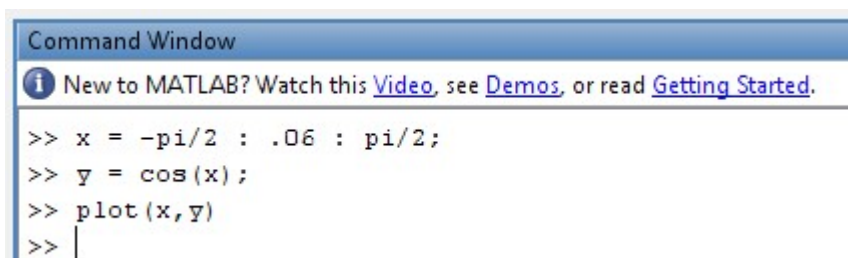
- **Command window**: At the ">>" command prompt, the user can enter the instructions to be executed. This is the main interface window.

- **Current directory**: Allows to browse and view the contents of the user's current directory. User programs must be located in this directory to be visible and therefore executable.

- **Workspace**: Allows to view the defined variables, their type, the size occupied in memory,… etc.

- **Command history**: History of commands the user has executed. It is possible to drag these commands to the command window.

The command window is the central window of the interface. It is from there that the user will be able to launch the commands interpreted by Matlab. The principle is simple and intuitive, the trick is to know the appropriate functions and to respect their syntax.

3.2. Graphic representation

Matlab libraries offer a very large number of functions for manipulating graphic objects. We present here only some basic principles, useful for the visualization of curves. If we focus particularly in this section on the 2-dimensional graphic representation, it is possible to go much further: 3D graphics (curves, meshes, surfaces ...), GUI editing (graphical user interface), animations, ...etc.

Let us plot the cosine function in the interval [-π/2, π/2] with a step of 0.06.


```
Command Window
(i) New to MATLAB? Watch this Video, see Demos, or read Getting Started.

>> x = -pi/2 : .06 : pi/2;
>> y = cos(x);
>> plot(x,y)
>>
```

Figure (3.2): Command window ; Source: own installed software (Matlab R2007b)
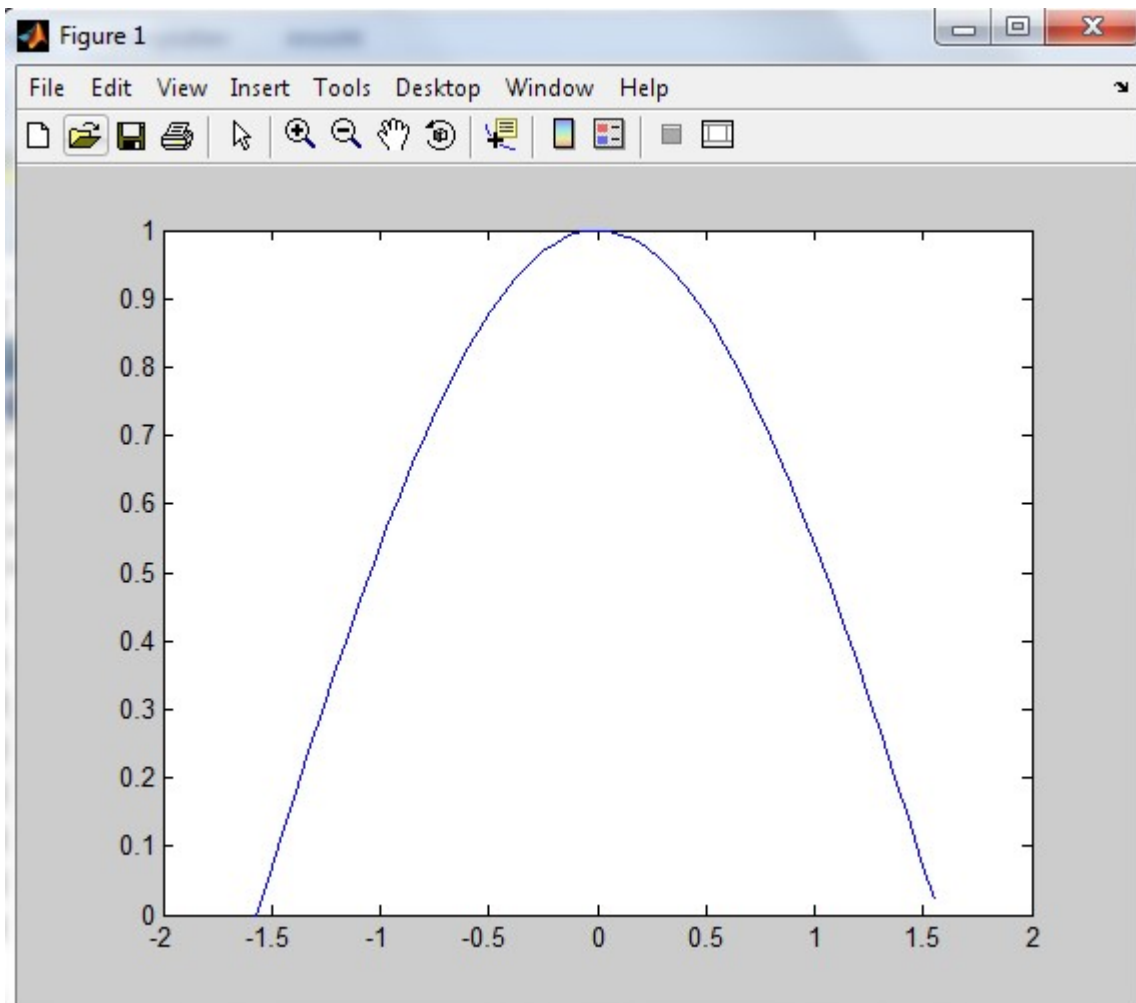
Figure (3.2.1): Cosine function in interval [-π/2, π/2] with a step of 0.06 ; Source: own installed software

3.3.   Simulink

Simulink is a software with a graphical interface for modeling, simulation and analysis of dynamic systems. Being integrated with Matlab, the two environments are perfectly compatible and the various functionalities are then directly accessible. Simulink is based on a graphical interface that allows easy and user-friendly construction of block diagrams. Each block making up the system is selected from a set of predefined libraries.

Simulink can be launched from the Matlab environment by clicking in the toolbar on the button or by typing simulink in the command window. The following window (Simulink Library Browser) appears:
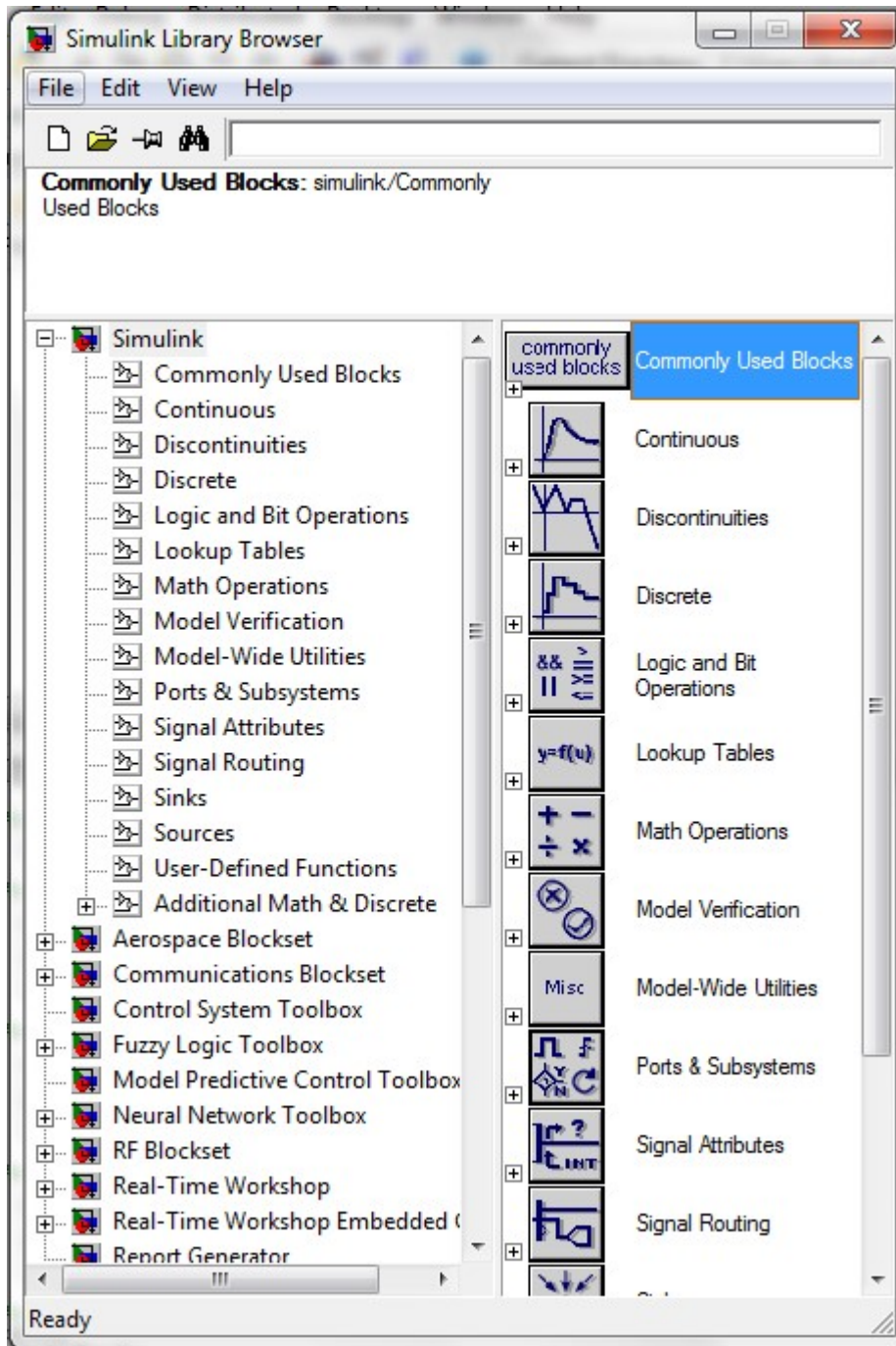
Figure (3.3.1): Command window ; Source: own installed software (Matlab R2007b)

The left column lists the available libraries. They are arranged by disciplines (Automatic, Aerospace, Communication, Signal processing, Fuzzy Logic, Real-Time,… etc.) and grouped together a set of functional blocks linked to a particular category of functions. When selecting a library, the blocks that compose it are displayed in the right part.

A new model is created by clicking on the blank sheet icon or on *File => New => Model menu*. An empty window appears, it will serve as a support to build our model.
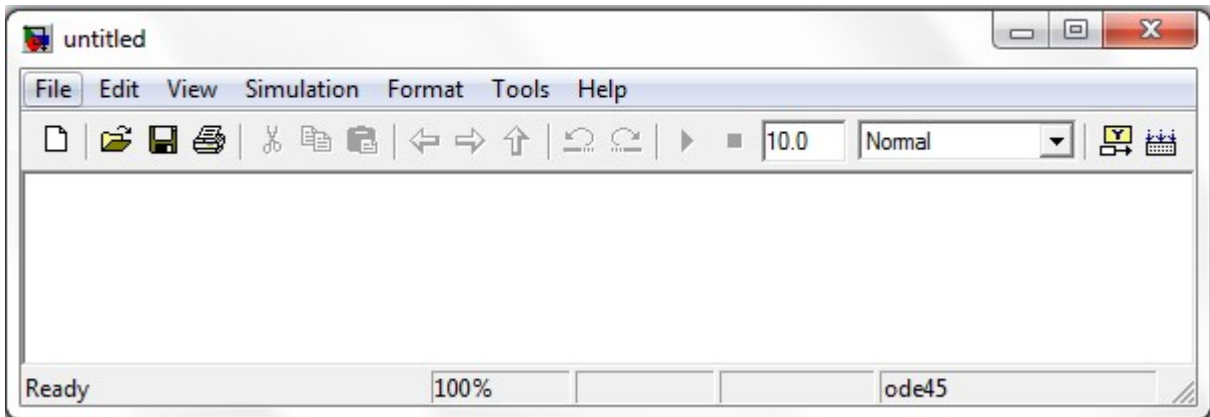
Figure (3.3.2): Model menu ; Source: own installed software (Matlab R2007 b)

The interface is intuitive and easy to use, a model is built from the functional blocks by drag and drop. The blocks are then interconnected by arrows drawn with the mouse (click and hold on a block's entry/exit and then release on another block's entry/exit). Each block can be edited (settings of its parameters) by double-clicking over it. This last action opens a dialog window in which a description of the block and configurable fields are given.
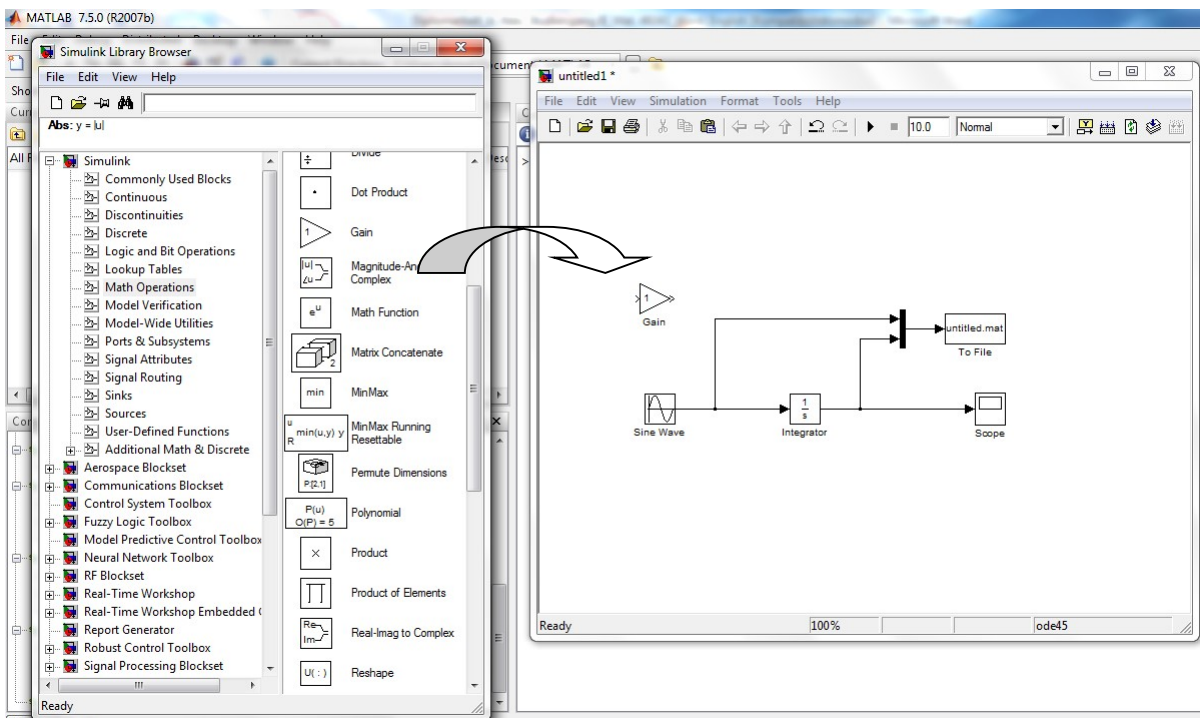
Figure (3.3.3): Blocks drawn per drag and drop ; Source: own installed software (Matlab R2007b)

Some blocks like Sine Wave can be set by clicking twice over them. After running the simulation, the response of the whole system can be observed by double-clicking over the oscilloscope.
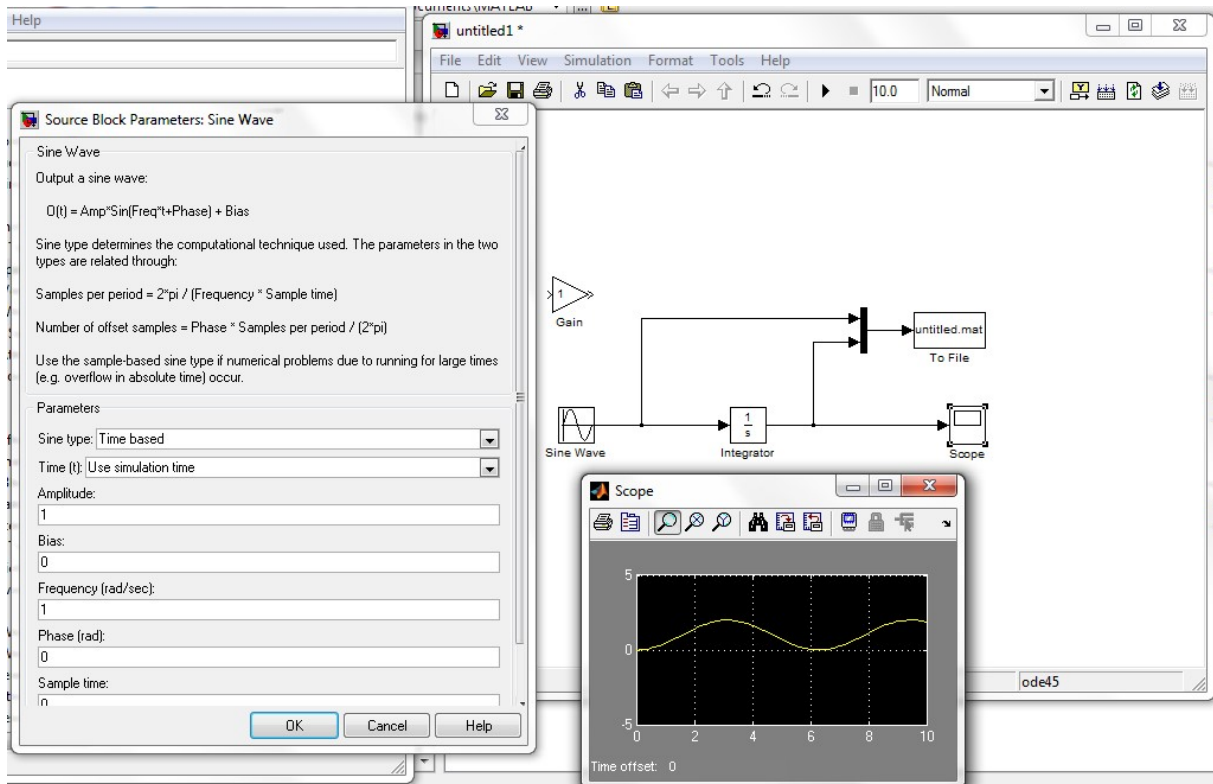
Figure (3.3.4): Scope representation: own installed software (Matlab R2007b)

4.   Simulation of a wind turbine using Matlab

4.1.   Operational management of a wind turbine

Wind turbines and wind farms are not only a comprehensive, but above all a long-term investment. The maximum yield can only be achieved during a certain period of time if smooth, perfectly and coordinated operation is guaranteed. A technical operator therefore takes all measures that serve to optimize and reduce costs in all areas, from the conclusion of contracts with insurers and maintenance companies to the permanent monitoring of the wind turbines including the commissioning of regular repair work. The quality of the technical operations management services is therefore the basis for the highest possible availability of wind turbines.

The remote monitoring of wind turbines, plays an essential role within the operator's portfolio. All system data relevant to the operation as well as yield data and details on the system status are recorded and evaluated. Regular inspections also provide a tangible on-site overview. The technical operations management also initiates and monitors all measures for troubleshooting. A careful comparison of target and actual data as well as error details also makes it possible to identify potential for improvement and to make the best possible use of wind turbine.

As already described, technical operations management is primarily about taking measures that guarantee a technically perfect condition of wind turbines and thus their highest possible availability. Technical operations can be summarized as follows:
- Care of wind turbine/wind farm around the clock.
- Coordination of repair and service measures as well as their monitoring.
- Regular reports to the operator of the wind turbine/wind farm.
- Maintenance and inspections at regular intervals.
- Long term organization and planning of the replacement of system components.
- Condition monitoring and documentation

In order to be able to make the right decisions as a technical operator, it is important to correctly interpret and evaluate malfunctions and fault reports. Their analysis provides initial information about the availability of wind turbines. Fault messages can be classified

according to fault groups, so that the different messages can be clearly interpreted. The classification takes place, for example in fault groups such as hydraulics, pitch, operator stop or brake. The type and duration of the respective malfunctions are documented and are used to investigate the causes of the malfunction and to assess availability. Of course, maintenance and repair times also have an impact on the availability of wind turbines. Since downtimes mean a loss of yield, precise information on downtimes and their causes is extremely important: They not only reveal possible optimization potential, but also provide the operator with precise data on whether his wind turbine/wind farm is being operated economically.
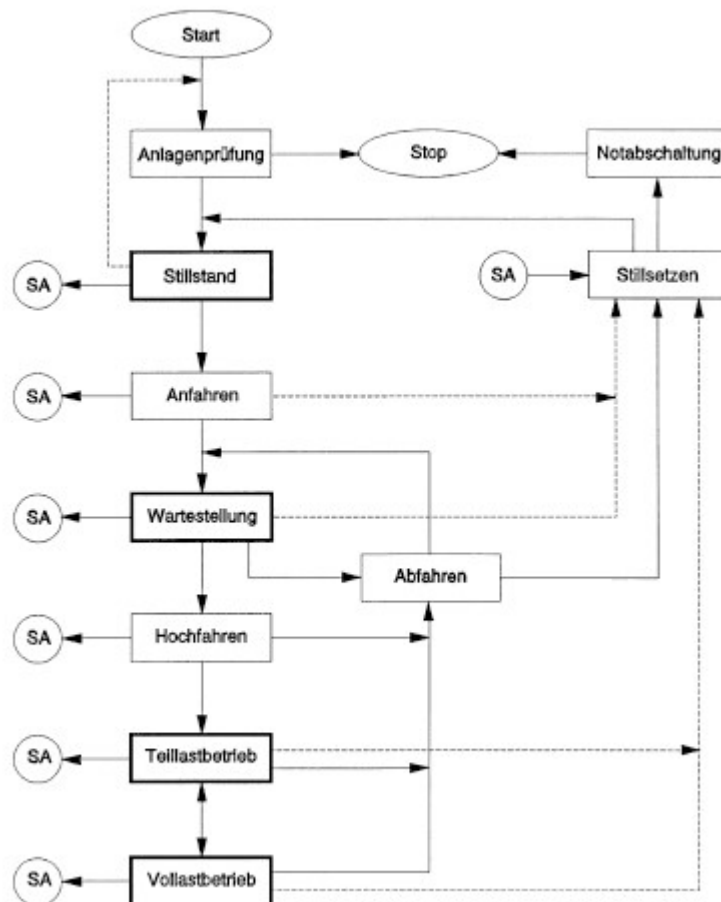
Figure (4.1): Structure of an operational management; Source: Literature [2]

When in operation, a wind turbine is fully functional. In this state, the automatic mode is switched on, the wind turbine is ready for use, works in the manner intended for it and has no malfunctions.

There are two types of operating states:
- Temporary operation: This state is limited in time and monitored. An error message occurs after a defined time has been exceeded.

- Stationary operation: No state is monitored. This operation is achieved when all normal operating conditions are met.

Anlagenprüfung or system testing

After the operational management has been put into service, the wind turbine must be subjected to a system test. Different states of the operational sequence are queried and they are concluded with messages. If all messages are positive, the operational management can switch to standstill.

Stillstand or standstill

In this operating state, the rotor is in a stationary position and the brakes are activated. The electrical generator system is switched off and no current is flowing. This prevents switching to the start-up mode. A system check then runs and if all conditions are positive, it is possible to switch to start-up.

Anfahren or start up

When starting up, the wind turbine runs without load at rotor speed defined by the operational management. The conditions for stopping and waiting speed are checked. As soon as the waiting speed has reached the minimum, the waiting mode is switched on.

Wartestellung or waiting mode

In this state, all components of the wind turbine are ready for operation. The generator system is still switched off and there is still no current flowing. The conditions for starting up, shutting down and stopping are checked. If the waiting mode becomes too long, an error message appears. A change to the next operating state takes place after a positive check.

Hochfahren or drive up

If the speed of the wind is high enough, the rotor speed of the wind turbine can be increased to a certain value. Once the value has been reached, the generator system can be connected to the supply network. During drive up, all conditions are checked and if they are all positive, it goes to the next operating state.

Teillastbetrieb or partial load operation

The generator system feeds electricity into the supply network. The rotor remains limited by speed control. Even in partial load operation, all conditions for the next operating state are checked.

Volllastbetrieb or full load operation

The change from partial load operation to full load operation only takes place via wind speed when this has reached a certain value. The termination conditions and messages are constantly checked.

4.2. Simulation using Matlab

The **G**raphical **U**ser **I**nterface **D**evelopment **E**nvironment (GUIDE) is used for the creation of a **G**raphical **U**ser **I**nterface (GUI) for a Matlab program. GUI allows the user to interact with a Matlab program, thanks to different graphic objects (buttons, menus, check boxes,…etc). By saving GUIDE two files occur:

- The figure file or **FIG-file** with the suffix **.fig** describes the layout by giving graphical information.
- The code file or **M-file** with the suffix **.m** which contains Matlab functions and a number of subfunctions. This file enables the functionality of GUI and controls its behaviour.

How to start the simulation with GUIDE

1. Open up Matlab . Go to the command window, type in guide and press the enter Key.
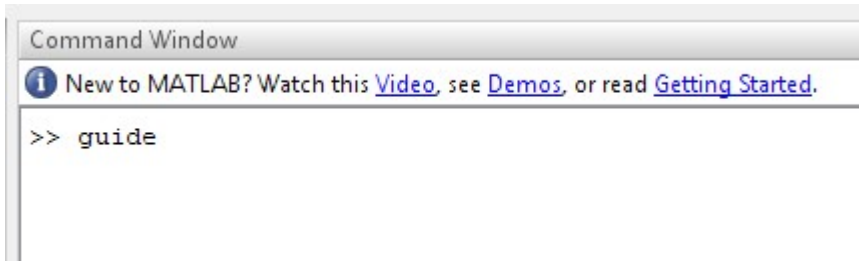
2. Choose the first option Blank GUI (Default) and click OK.
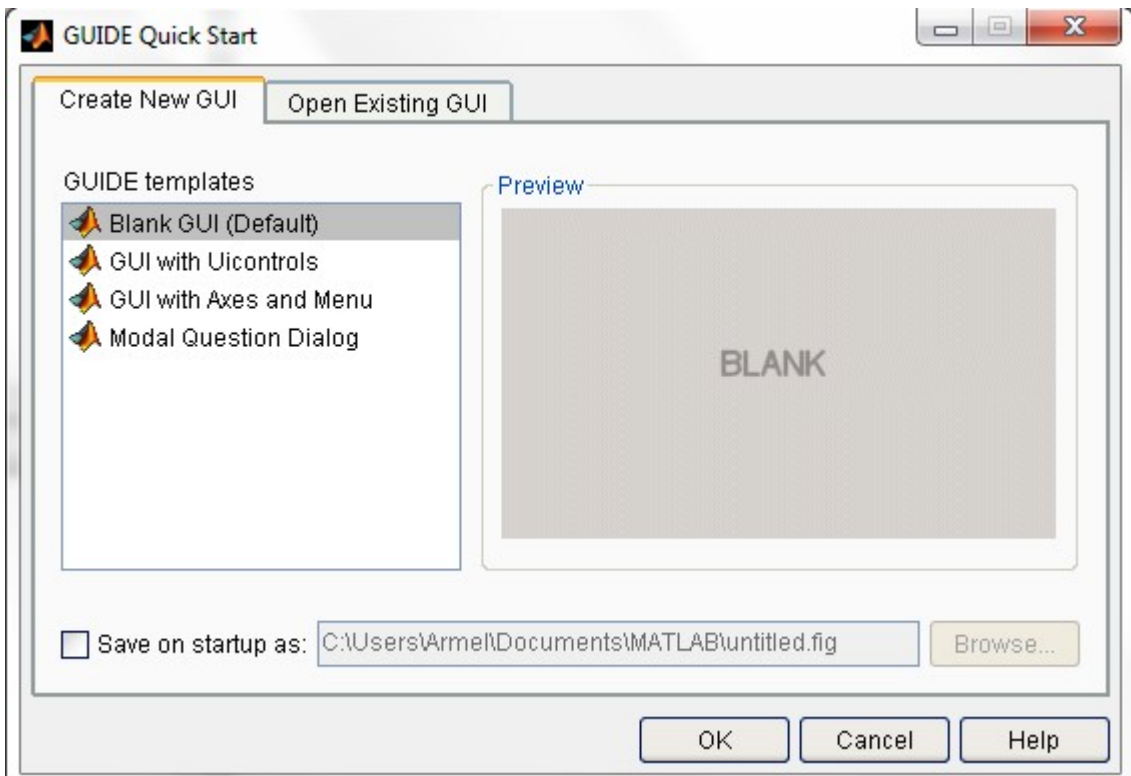
3. The following GUIDE window appears.
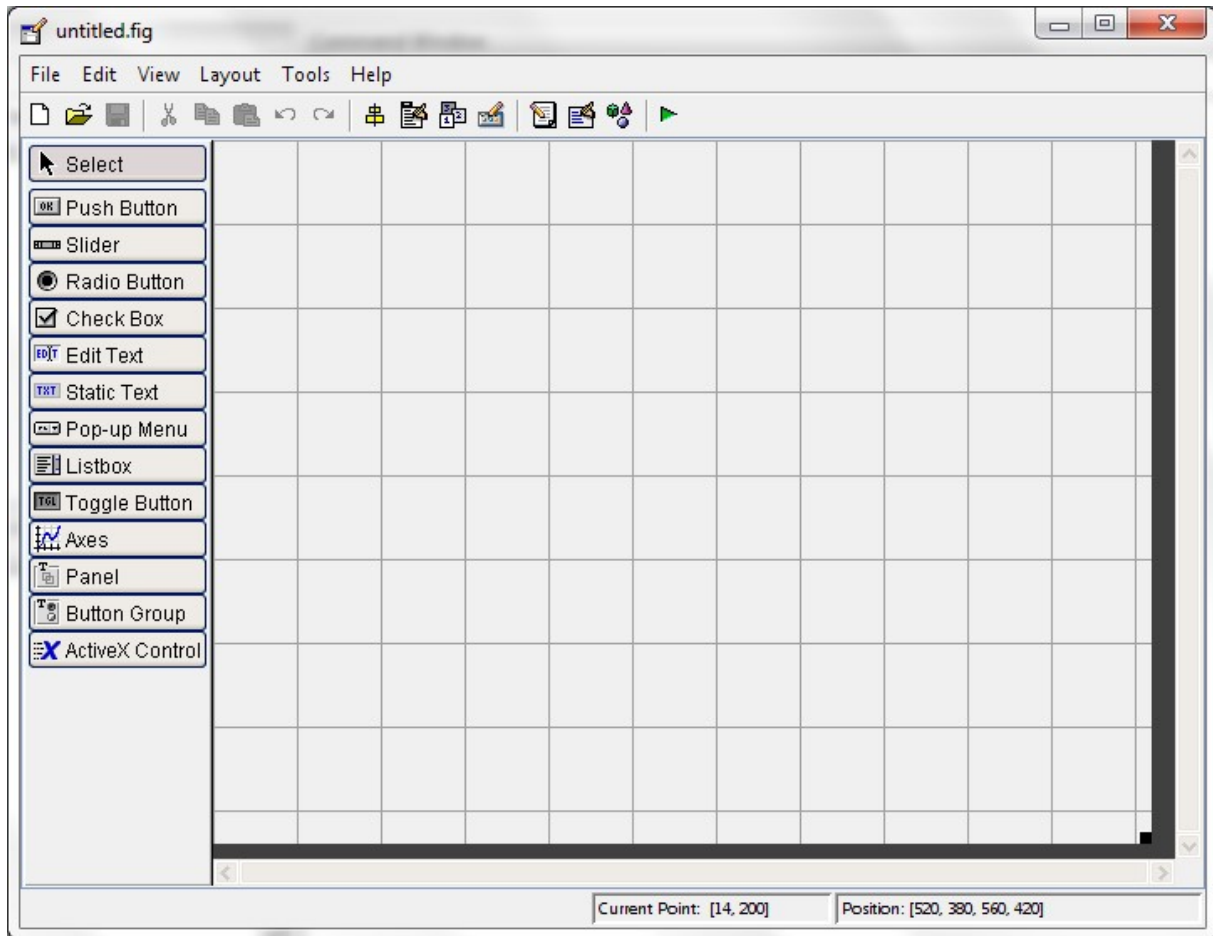
GUI objects can be created by using the buttons on the left (see GUIDE window above):

Push Button: A button being activated when the user clicks on it.

Slider: By adjusting the position of the slide a number can be entered.

Radio Button: Can be selected/unselected to change state.

Check Box: By ticking on the Box its state can be changed.

Edit Text: Allows the user to type text into the window.

Static Text: Displays items to get labeled.

Pop-up Menu: Gives the user the possibility to select options.

Listbox: Lists items that can be selected and scrolled.

Toggle Button: Once pressed, it's possible to switch between options.

Axes: A Surface used to display 2- or 3- dimensional graphics.

Panel: Visually controlled groups.

Button Group: Enables Radio Buttons or Toggle Buttons to act together by just selecting one each time.

ActiveX Control: Allows a windows program to insert an ActiveX.

4. Add and adjust GUI objects per drag and drop onto the GUI figure.
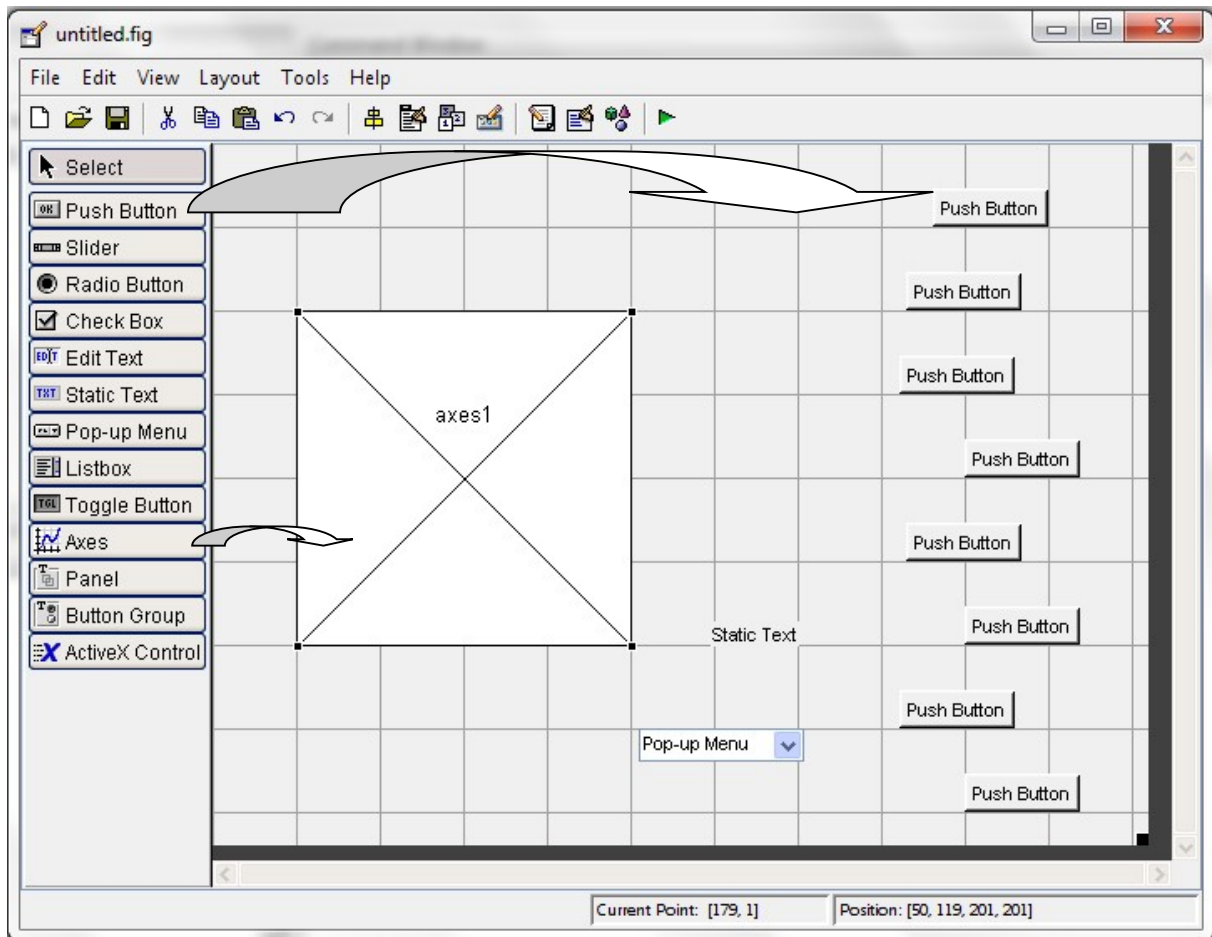
If necessary the Push Buttons can be aligned firstly by pressing *Strg*, clicking over them and secondly by selecting on the menu bar *Tools => Align Objects.*
Align Objects allows to set the space between Push Buttons vertically and horizontally as seen in the figure below.
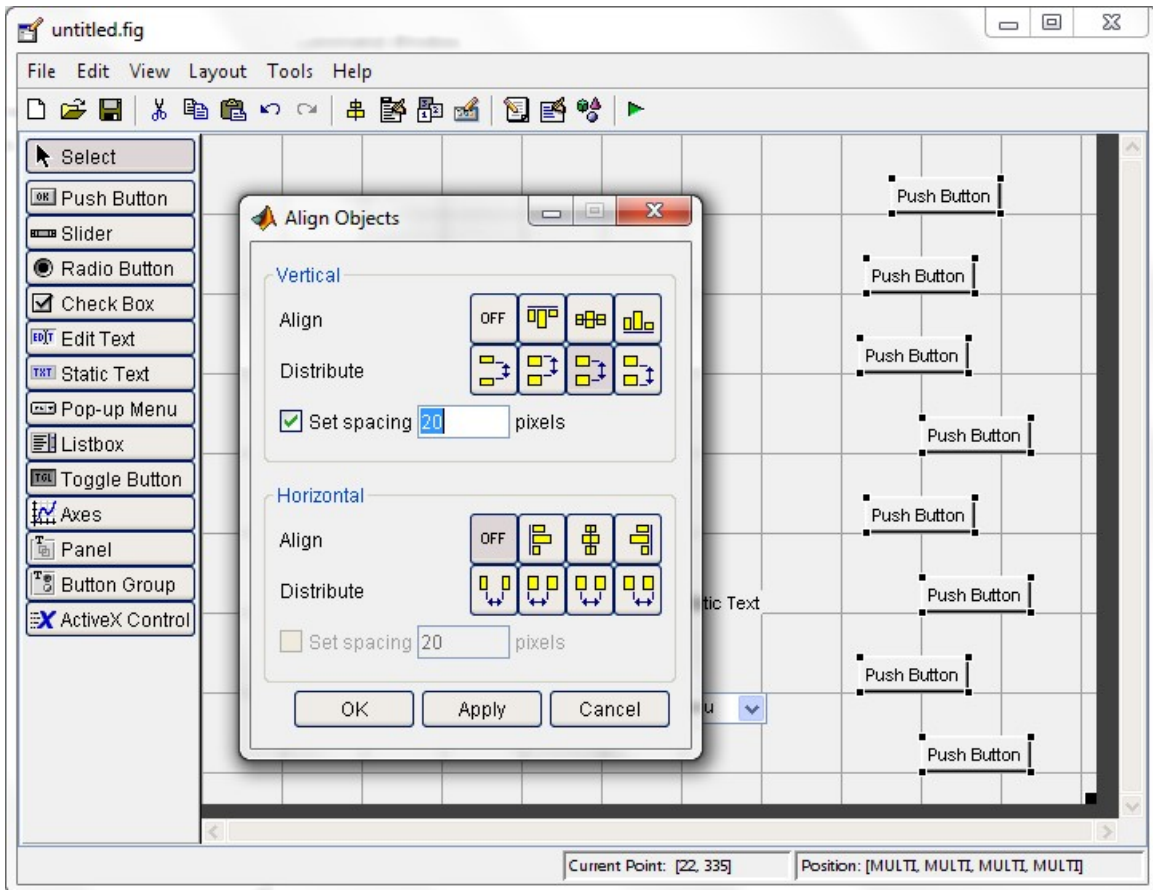
5. Double click on Push Buttons, select *String* and assign a new value to the existing one.
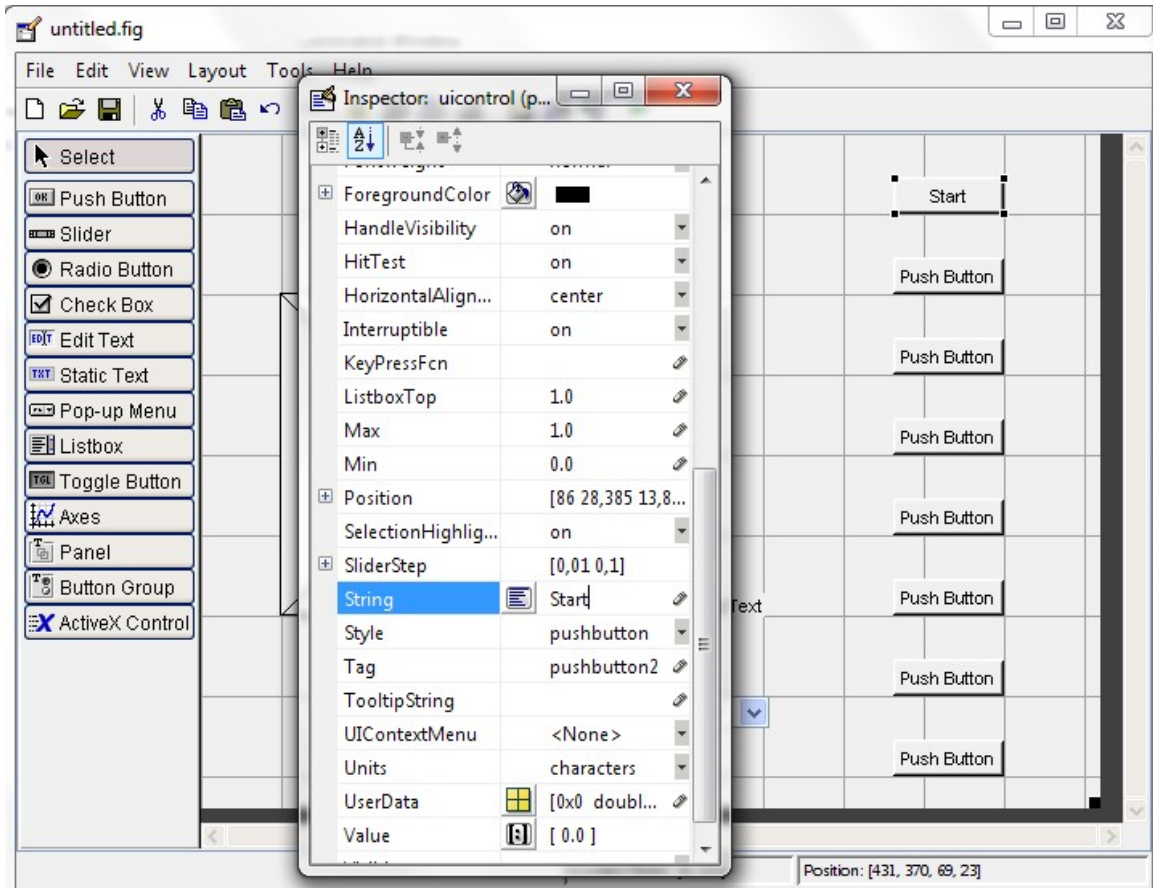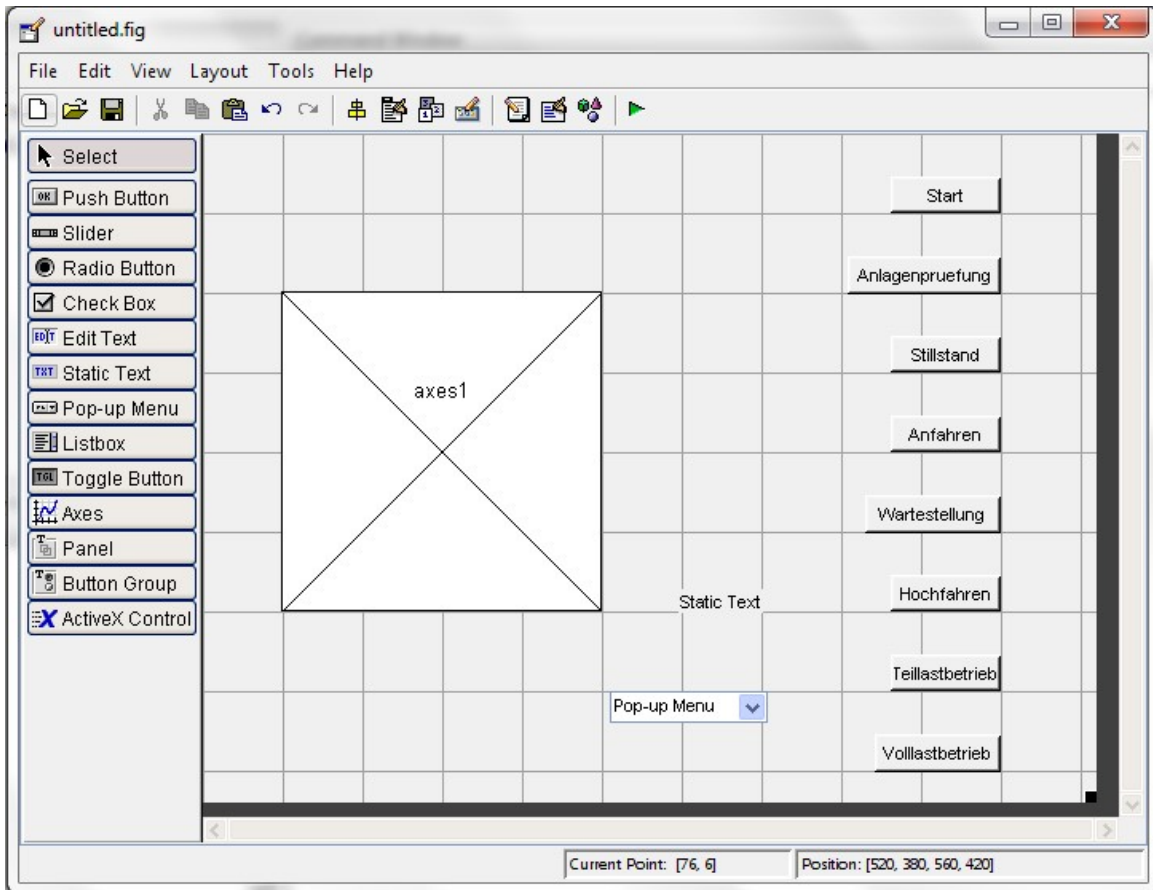
6. Matlab functions peaks, membrane, sinc to replace the value with the word Pop-Up.
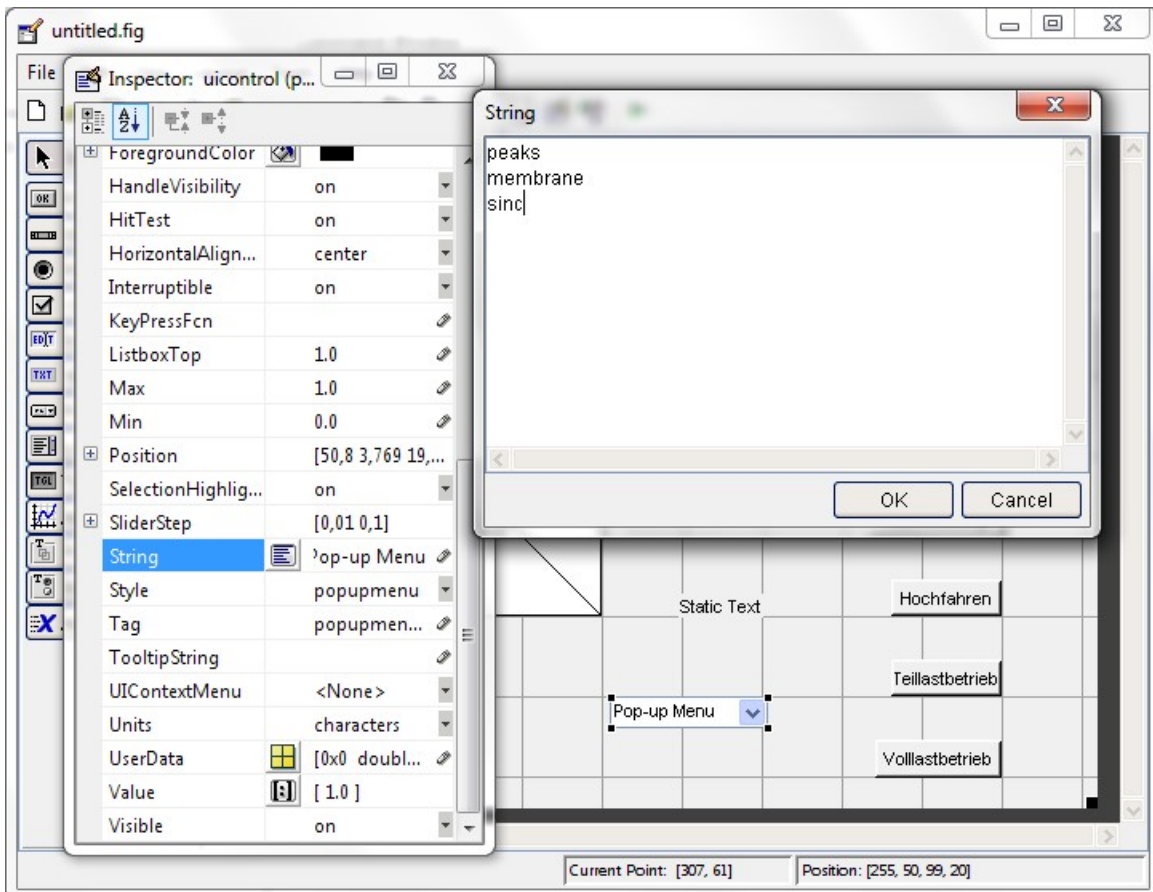
7. Pop-up menu to be labeled as Select Data.
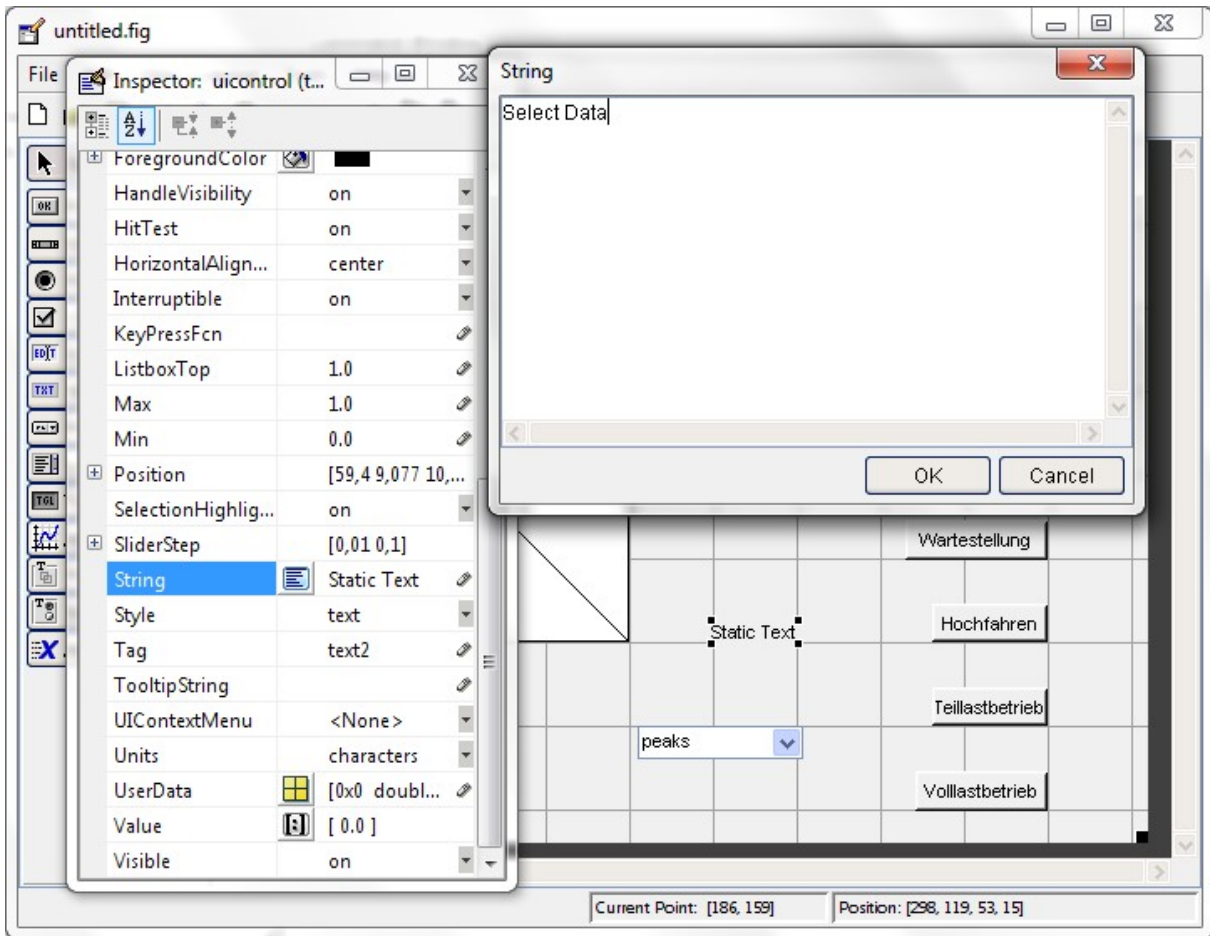
8. Saving the GUI to a file.

GUI can be saved under any file name and Matlab generates automatically two files with extension .m and .fig.

- The **.fig-file** contains all the geometric information and all the properties of every GUI object put in the frame.
- The **.m-file** contains all the code for the GUI. That code creates and executes the GUI tool being made.

GUI stores the two files in the Matlab folder and loads them into the Matlab editor.

Fig-File; Source: own installed software (Matlab R2007b)

M-File; Source: own installed software (Matlab R2007b)

After having saved the files, GUI can be launched by selecting *Tools => Run* or simply by clicking on the green icon ▶ seen on the GUIDE editor below .
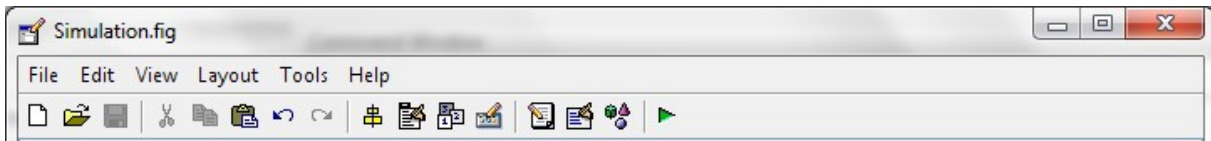
GUIDE displays the following dialog box. To continue click on "Add to Path "
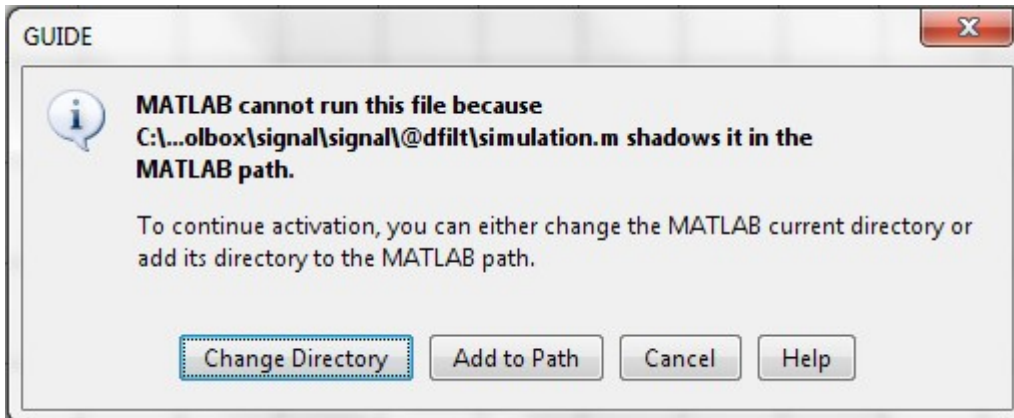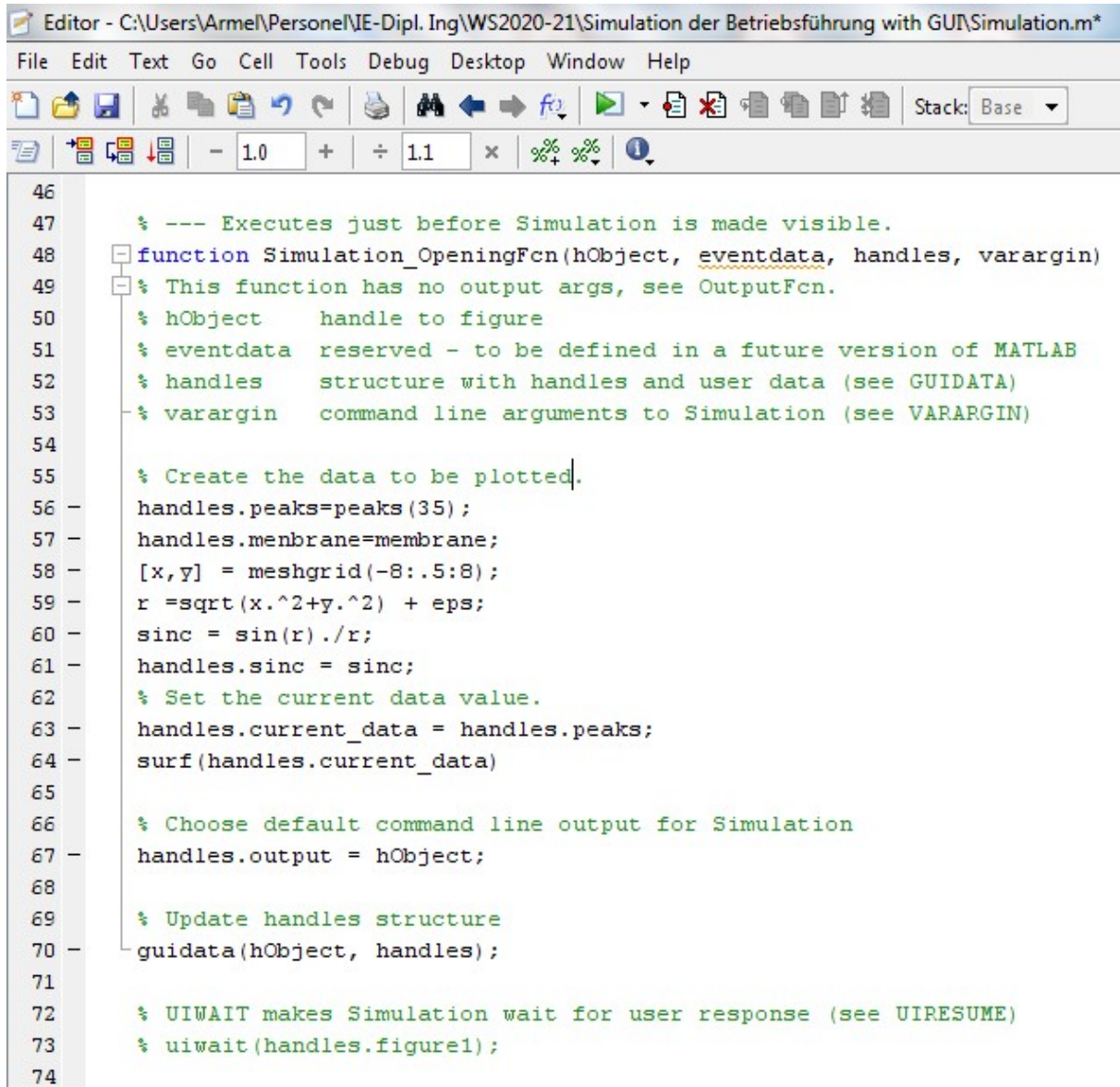
At this stage the simulation is not responding/working. To have it functional, multiple codes should be added to the m-file.
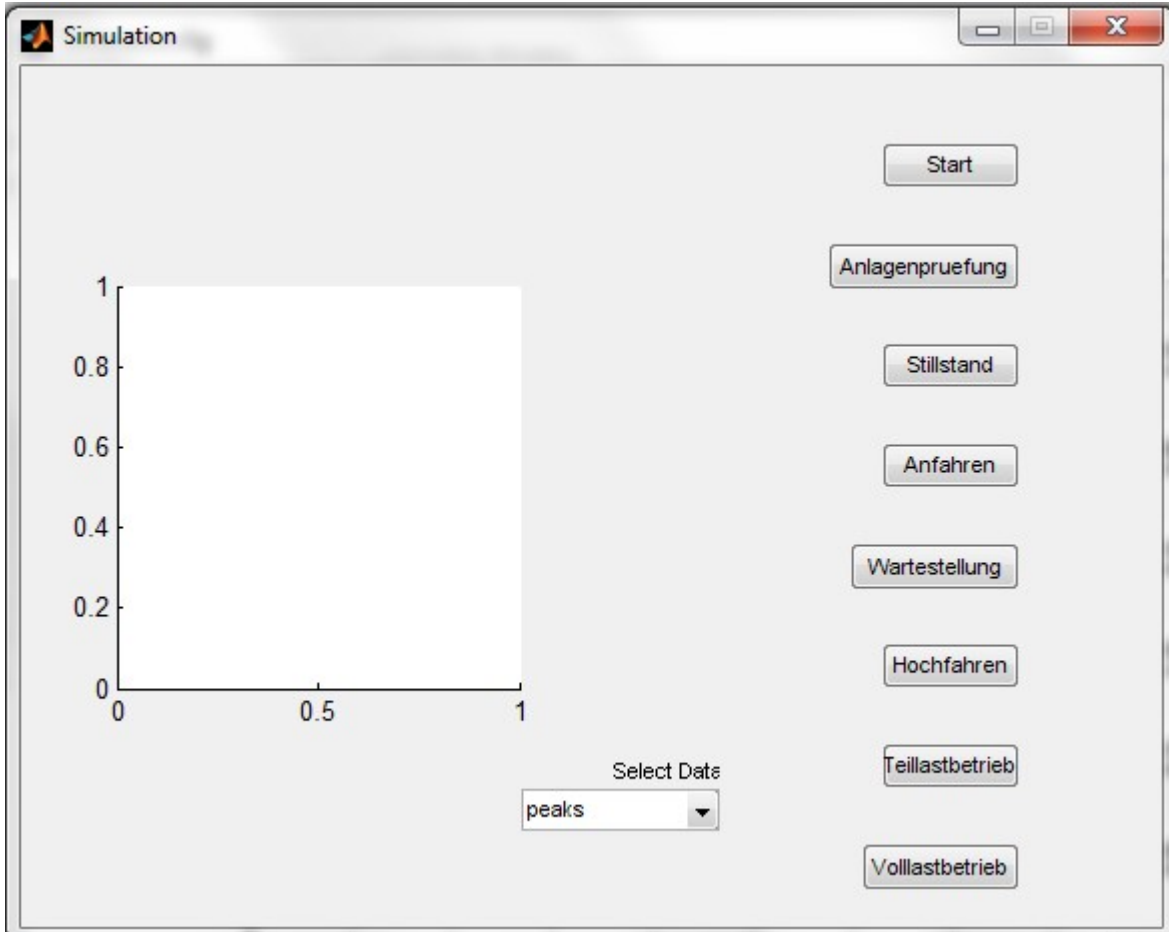
To generate the graphic to be plotted a code should be added to the opening function immediately after the **line 53** *"% varargin command line arguments to simulation"* and before the **line 66** *"% Choose default command line output for Simulation"*.

```
Editor - C:\Users\Armel\Personel\IE-Dipl. Ing\WS2020-21\Simulation der Betriebsführung with GUI\Simulation.m*

File   Edit   Text   Go   Cell   Tools   Debug   Desktop   Window   Help

46
47       % --- Executes just before Simulation is made visible.
48      function Simulation_OpeningFcn(hObject, eventdata, handles, varargin)
49      % This function has no output args, see OutputFcn.
50      % hObject      handle to figure
51      % eventdata    reserved - to be defined in a future version of MATLAB
52      % handles      structure with handles and user data (see GUIDATA)
53      % varargin     command line arguments to Simulation (see VARARGIN)
54
55      % Create the data to be plotted.
56      handles.peaks=peaks(35);
57      handles.menbrane=membrane;
58      [x,y] = meshgrid(-8:.5:8);
59      r =sqrt(x.^2+y.^2) + eps;
60      sinc = sin(r)./r;
61      handles.sinc = sinc;
62      % Set the current data value.
63      handles.current_data = handles.peaks;
64      surf(handles.current_data)
65
66      % Choose default command line output for Simulation
67      handles.output = hObject;
68
69      % Update handles structure
70      guidata(hObject, handles);
71
72      % UIWAIT makes Simulation wait for user response (see UIRESUME)
73      % uiwait(handles.figure1);
74
```

Code for plotting a graphic; Source: Literature [3]

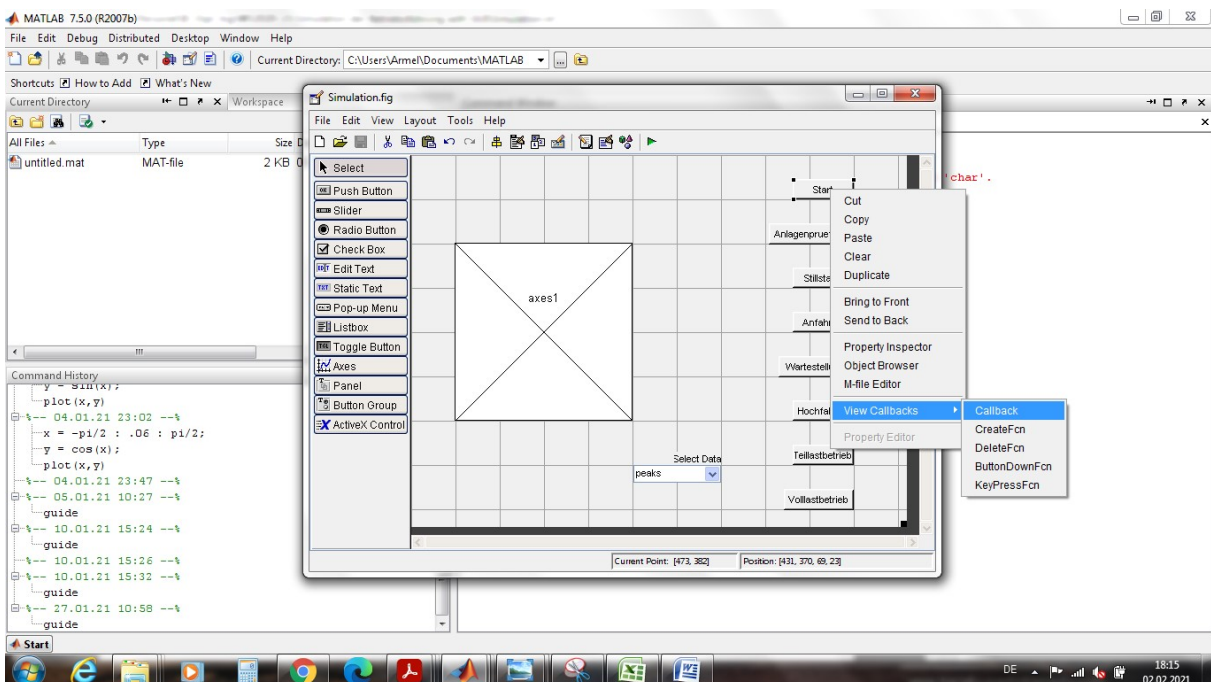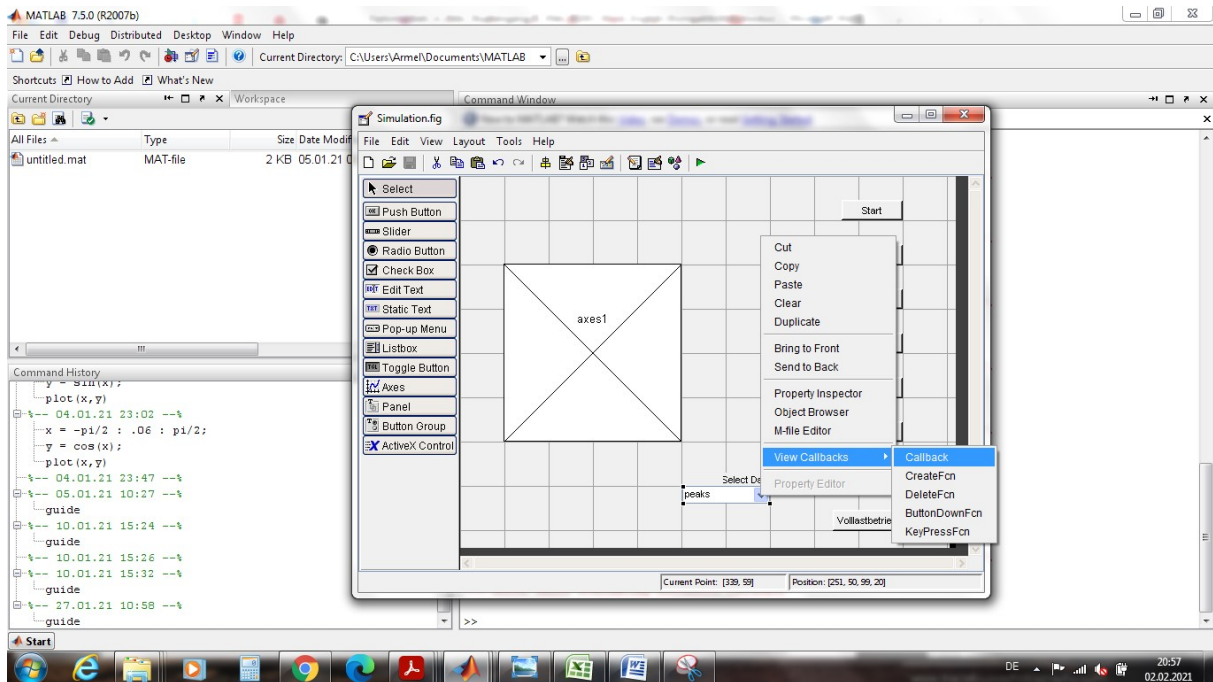|	
hObject:	Every GUI object (Push Button, Slider, Pop-up Menu, Axes…etc) is represented by a "handle" variable.
handles:	Coded structure of a GUI object and containing data stored in it. handles is used to communicate with the GUI object through the commands *get* und *set.*
varargin:	"**var**iable **arg**ument **in**put" can be used to send in a different number of arguments for different function calls.

eventdata: Is empty for most callbacks but for some it gives more information about what triggered the callback.

By running the simulation the following graphic can be created:
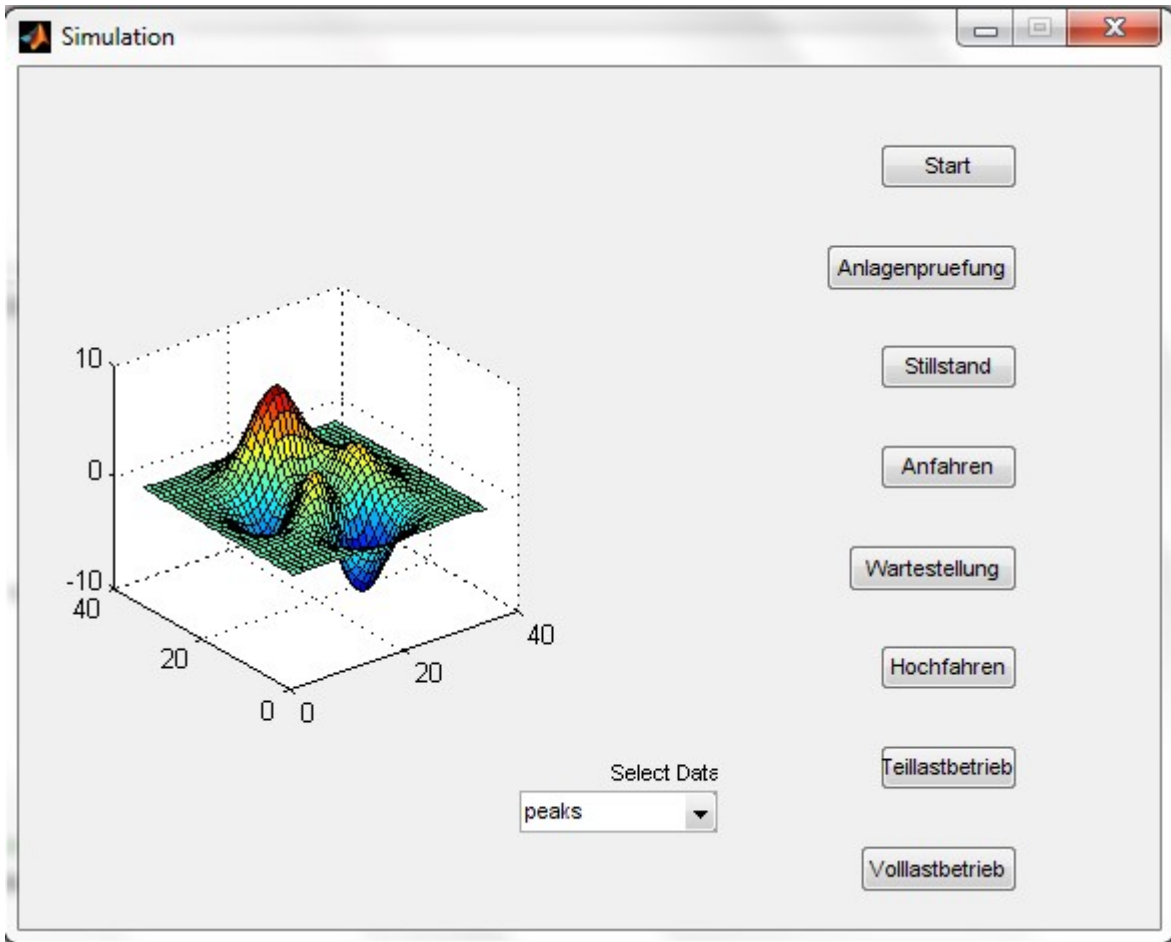
To activate each Push Buttons, a Callback is to be selected for each of them as seen below:

By selecting the Callback for Start, the Cursor will then take us to the following code block.

After the **line 91** "% *handles structure with handles….*" the following code is to be added:

```
93        % Display start plot of the currently selected data
94 -       start(handles.current_data);
```

And the same procedure should be repeated for the remaining Push Buttons.

To activate the Pop-up Menu a Callback should be selected as follow:

And a code should be added to the M-file.


```matlab
158
159    % --- Executes on selection change in popupmenu2.
160    function popupmenu2_Callback(hObject, eventdata, handles)
161    % hObject      handle to popupmenu2 (see GCBO)
162    % eventdata    reserved - to be defined in a future version of MATLAB
163    % handles      structure with handles and user data (see GUIDATA)
164
165    % Determine the selected data set.
166    str = get(hObject, 'String');
167    val = get(hObject, 'Value');
168    % Set Current data to the selected data set.
169    switch str{val};
170        case 'peaks' % User selects peaks.
171            handles.current_data = handles.peaks;
172        case 'membrane' % User selects membrane.
173            handles.current_data = handles.membrane;
174        case 'sinc' % User selects sinc.
175            handles.current_data = handles.sinc;
176    end
177    % Save the handles structure.
178    guidata(hObject,handles)
```

Code for the activation of Pop-up Menu; Source: Literature[3]

At this stage the expectation is to have the graphic (page 38) changing its structure by clicking on one of the Push Buttons (Start, Anlagenpruefung etc…). Unfortunately the activation of the Push Buttons isn't working and there are multiple errors appearing onto the command window as seen in the interface below.

```
Command Window
ⓘ New to MATLAB? Watch this Video, see Demos, or read Getting Started.

    gui_mainfcn(gui_State, varargin{:});

??? Error while evaluating uicontrol Callback

??? Reference to non-existent field 'current_data'.

Error in ==> Simulation>pushbutton6_Callback at 136
Wartestellung(handles.current_data);

Error in ==> gui_mainfcn at 96
        feval(varargin{:});

Error in ==> Simulation at 42
    gui_mainfcn(gui_State, varargin{:});

??? Error while evaluating uicontrol Callback

??? Reference to non-existent field 'current_data'.

Error in ==> Simulation>pushbutton7_Callback at 145
Hochfahren(handles.current_data);

Error in ==> gui_mainfcn at 96
        feval(varargin{:});

Error in ==> Simulation at 42
    gui_mainfcn(gui_State, varargin{:});

??? Error while evaluating uicontrol Callback

>>
```

The reason for these errors is that the Push Buttons are not defined and not represented by a ''*handle*'' variable also called *hObject.* To fix the problem the Push Buttons have to be stored in the *handles* structure.

Unfortunately the remaining time doesn't allow me to look further into the code and to conclude this simulation successfully.

5. Bibliography

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