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ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF ELECTRICAL AND

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DEPARTMENT OF CONTROL ENGINEERING

WIND FARM LAYOUT OPTIMIZATION USING GENETIC ALGORITHM AND PITCHANGLE CONTROL

A thesis submitted to Addis Ababa Institute of Technology, School of GraduateStudies, Addis Ababa University

In partial fulfillment of the need for the Degree of Master of Science in EE (Electrical Control Engineering)

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Abstract

In this study, MATLAB is used to develop wind farm layout optimization and pitch angle control methods for the wind energy system. The upstream wind turbine reduces the wind speed that passes through the downwind turbine when numerous wind turbines are arranged in close proximity and at random in a wind farm. The wake effect is the name for this phenomena. This effect has an impact on the wind farm's energy production. As a result, while planning and constructing effective wind farms, an optimum layout that takes into account the wake effect is critical. This research proposes a genetic algorithm-based wind farm layout optimization methodology for optimal power output while minimizing wake loss. As a result, power output has increased from 94.25 percent to 96 percent. SIMULINK findings from prior studies for 26, 30, and 32 turbines in a 2000m2 farm area are used to validate this.

The change in wind speed is the other most significant difficulty in wind energy systems.

The power level rises above the authorized safe level when the wind speed exceeds the rated value of the wind turbine. As a result, the wind turbine rotor is subjected to a highly nonlinear aerodynamic load.

This load causes blade fatigue and vibration, resulting in rotor blade damage. To overcome the load and manage the quantity of aerodynamic collected power, an Adaptive Fuzzy PID pitch angle controller is developed in this article. Furthermore, it improved the transient stability of the wind energy system.

When compared to the PID controller, simulations show that the suggested controller is superior in terms of feasibility, overshoot, and settling time.

Keywords: Genetic Algorithm, wake effect, Pitch Angle PID controller, Adaptive Fuzzy-PID

ACKNOWLEDGMENTS

First and foremost, Glory to the Almighty God and His Mother, for keeping me, and giving me strength to complete my study and in every step of my life.

I would like to express my warm thankfulness to my advisor Dr.Dereje Shiferaw, for his generous and constant support, And for encouraging me to look more into the area of Wind Energy

Also, I would like to deal special thanks to my little brother, Eyob Fanta who was the greatest inspiration on my thesis work until the end of his life on earth. My heart pains me to learn that he is no more. May his soul rest in peace in Heaven!

ACRONYMS

WF	Wind farm
WT	Wind Turbine
WFLO	Wind farm layout Optimization
WFLOP	Wind farm layout optimization problem
AEP	Annual Energy Production
EEPCo	Ethiopian Electric Power Cooperation
WTG	Wind Turbine Generator
HAWTs	Horizontal-axis wind turbines
PC	Pitch Control
PID	Proportional Integrator Derivative
FLC	Fuzzy Logic Control
WTG	Wind Turbine Generator
WASP	Wind Atlas Application Program

NOMENCLATURES

Nt *(*N*)*	Number of wind turbines
u	Velocity in the wake of a wind turbine
uo	Free stream velocity
a	Axial induction factor
x	Downstream distance from the wind turbine
ro	Rotor radius of the wind turbine
rd	Wake radius at the downwind plane of the wind turbine
CT	Coefficient of the wind turbineE Energy
Z	Hub height of the wind turbine
Zo	Surface roughness height of the site considered for the wind farm
r	Radius of the wake
ή	Efficiency of the wind turbine
A	Area swept by the rotor of the wind turbine
ρ	Density of air
GW	Giga Watt
MW	Mega Watt
P	Power
Cp	Power Coefficient
GWh	Giga Watt hour
ß	pitch angle

List of figures

List of tables

CONTENTS

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Due to the energy deficit, environmental concerns, and the fact that wind turbine technology is a viable source of renewable energy, wind energy has received a lot of attention recently.

Wind energy is one of the renewable energy systems with the lowest cost of electricity production and the most important resource available, and there are major essential arguments for its use around the world, such as Wind energy is one of the renewable energy systems with the most important resource available. Wind turbines, unlike nuclear power stations, emit no CO2.

Wind turbines are substantially less expensive than many other types of power plants, particularly when compared to nuclear power plants. Wind farms occupy area that may be used for other purposes, including as agriculture. The kinetic energy in the wind can be converted into mechanical energy, which can subsequently be converted into electrical energy by a wind turbine generator.

A wind turbine is a device that turns the energy of the wind into electricity.

Blades are coupled to a hub that spins in reaction to the force of the wind on the blades to achieve this. A wind park is a collection of wind turbines that are grouped together to form a wind-powered power plant. The fixed costs (administration costs, electrical network-related costs, and project development costs) of a wind park cover a significantly larger investment, making wind energy competitive [2].Wind farms are easy to operate and maintain because all of the wind turbines are in one location. The downsides of wind farms, on the other hand, include power losses owing to the wakes of the wind turbines and greater wind turbine maintenance due to increased turbulence in the wind farm.

The wind park's design is influenced by a number of elements. This includes everything from the wind farm's maximum desired installed capacity to site limits, noise assessments for noise-sensitive homes, visual impact, and total cost. When designing a wind farm, the primary goal is to increase power production while lowering the total cost of the project. The process of optimizing the architecture of the wind farm is known as "micro-siting." The potential of wind turbine technology, on the other hand, cannot be realized unless the wind farm layout is effective. The problem with wind park layout optimization is that it's difficult to locate the best layout among a large number of options. Many nature-inspired algorithm techniques have been utilized to address non-linear optimization problems in a variety of domains, and when employed for wind farm layout optimization, they have demonstrated promising results. Despite this, there hasn't been much research into whether genetic algorithm models can improve the results. Turbine settlement in a wind power plant is improved in this study using an objective function that expresses the value per unit of electricity produced by the wind park for a given wind distribution function. A model of wind fluctuations in speed and direction averaged over a year is represented by the wind distribution function. A genetic algorithm is working for optimizing the location of wind turbines. For simulating wind turbine waves in the wind, an analytical wake model is used. farm.[1]

Moreover for optimal power production, for maximum power tracking, and for protecting the wind turbine from damage pitch angle control system is introduced in this paper. The principle behind pitch angle control is that the blades move away from the wind rather than into it. It is possible to achieve this by lowering the pitch angle ß. When the wind speed exceeds the rated value, the angle ß is reduced to reduce the pressure on the blade's lower surface and, as a result, the torque force. The rotor speed and hence output power will be reduced when the torque force decreases, allowing the rated value to be maintained. When the wind speed is less than the rated value, the angle ß is increased to optimize the output power and keep it at the rated value. [24]

1.2 Statement of the Problem

The goal of wind farm layout optimization is to locate the optimal wind turbine sites inside a wind farm. The problem with grouping wind turbines in a wind farm is that some turbines are placed in the wake of others (wake effect). Wake interference, which is generated at random by upstream turbines, reduces wind speed and intensifies turbulence on downstream turbines. The wake effect results in a drop in wind speed in the wake-affected zone. Because wind energy is related to the third power of wind speed, even a minor change in wind speed can have a significant impact on the wind turbine's output power. The wake-affected wind farm's total power production is lowered by 25% to 45 percent compared to the wake-unaffected wind farm [4].The economic value of wind farm projects is impacted by these high power losses, which causes wind energy consumption to be delayed. Furthermore, when the wind speed. As a result, the wind turbine rotor bears an aerodynamic load that is highly nonlinear. This load causes blade fatigue and vibration, resulting in rotor blade damage.

This study provides a genetic algorithm layout optimization method for reducing wake power losses and maximizing energy capture. An adaptive fuzzy PID controller, on the other hand, is designed to handle with a turbine's nonlinear characteristics while also reducing the hundreds on the blades.

1.3 Objectives of the study

1.3.1 General objectives

The goal of this research is to improve wind farm performance by reducing the wake effect and to design a wind farm optimization framework in terms of wind farm layout and pitch angle control system.

1.3.2 Specific Objectives

- optimal wind farm design will tackle a critical problem: wake power losses (Genetic Algorithm)
- To be able to find a more efficient architecture that results in increased energy output and profit.
- Describe the most accurate mathematical model for calculating the impact of wake effects on energy output. • To select best algorithm in comparison with other algorithms which is intended to be applied to any land shape,
- To develop controlling strategy of the pitch angle(Adaptive Fuzzy Logic Control)
- To justify pitch angle control which provides an effective method of regulating the aerodynamic power and loads produced by the rotor, when the wind speed is above rated.

1.4 Methodology

To achieve the objectives of this study, the relevant methodologies have been used along with the estimated power output at the site Adama II with 102 wind turbines. Literature of relevant materials related to wind energy and its resource assessment methods are reviewed to come up with the global trends regarding wind farm layout optimization.[1]

1.5 Significances of the Study

This study's findings will be useful for the following reasons:To a BSc and MSc student's academic reference.It is also intended that the findings of this study may assist local wind farms in re-evaluating their power extraction and control methods, as well as taking steps to address any deficiencies.The analysis will also be more relevant for the new wind farm projects that will be built. in the right layout.

1.6 Scope of the Study

The lack of adequate local researches for local wind farms in the area of layout optimization of wind turbines is one of the limitations of this study. And also the real data is not obtained from any local wind plants. For this reason, the study is going to be carried out by taking sample data from previous research papers.

1.7 Structure of the Thesis

The thesis is organized as follows:

Chapter One describes the background and introduction of the research work followed by the significance of the study under the problem statement, objectives, and methodology.

Chapter Two presents literature reviews and the theoretical background of wind energy extraction, wind speed, wind direction, and wind power.

Chapter Three presents the construction of wind farms; wake models cost model and power calculation.

Chapter Four describes the optimization methodology, the theory of genetic algorithm, and the way of optimization.

Chapter Five presents Pitch Control Mechanisms, WT modeling, Pitch actuator modeling, PID, Fuzzy and Adaptive Fuzzy-PID controllers design

Chapter Six describes Results, Discussions, and Implementation of Windfarm layout optimization and Pitch angle Control.

Chapter Seven presents the Conclusion, recommendation, and future works.

1.8 Summary of Wind Energy Terms

1.8.1 Wind Energy

Winds are created by the sun's erratic heating of the atmosphere, irregularities on the surface, and hence the world's rotation. The earth's terrain, bodies of water, and vegetative cover all influence wind flow patterns. When "harvested" by modern wind turbines, this wind movement, or motion energy, is frequently used to generate electricity [19].Wind is affected by topographical features, time of day, season of the year, and height above the earth's surface, as well as weather and local landforms. Knowledge of wind characteristics will aid in the optimization of wind turbine design, the development of wind measuring systems, and the selection of Wind Farm sites [1].The measurement of wind variation is complicated and expensive equipment will be necessary; the two most significant elements for measurement are the wind speed and wind direction.

1.8.2 Wind Speed

Because wind speed varies with height, an equation that predicts wind speed at one height in terms of observed at another height is required.Because the flow of air above the ground is slowed by frictional resistance caused by surface features of the earth, wind speed is lower at surfaces near the ground than at higher distances above ground under normal conditions for flat terrain.

The main sources of wind speed retardation near the ground are the roughness of the ground itself or the presence of vegetation, buildings, and other structures over the ground [3].

Logs law, a logarithmic connection with height, describes the variation of wind speed with height above the flat surface ground.

The variation in wind speed has an impact on the farm's power generation since the rotor's rotational speed varies as the wind speed changes.In a 1.5 MW wind turbine, for example, when the wind speed falls below the cut-in speed of 3 m/s, the rotor will not rotate as the wind meets the rotor, indicating that no power is generated.Whereas, above 3 m/s, the power output will increase until the speed hits 12 m/s, at which point the power will achieve the rated power.The power does not grow in the range of 12 m/s to 20 m/s due to the electrical generator's and control scheme's capacity limitations.

For safety concerns, the turbine shuts down when the speed exceeds the cut off speed (20 m/s), as shown in Figure1.1 [4].

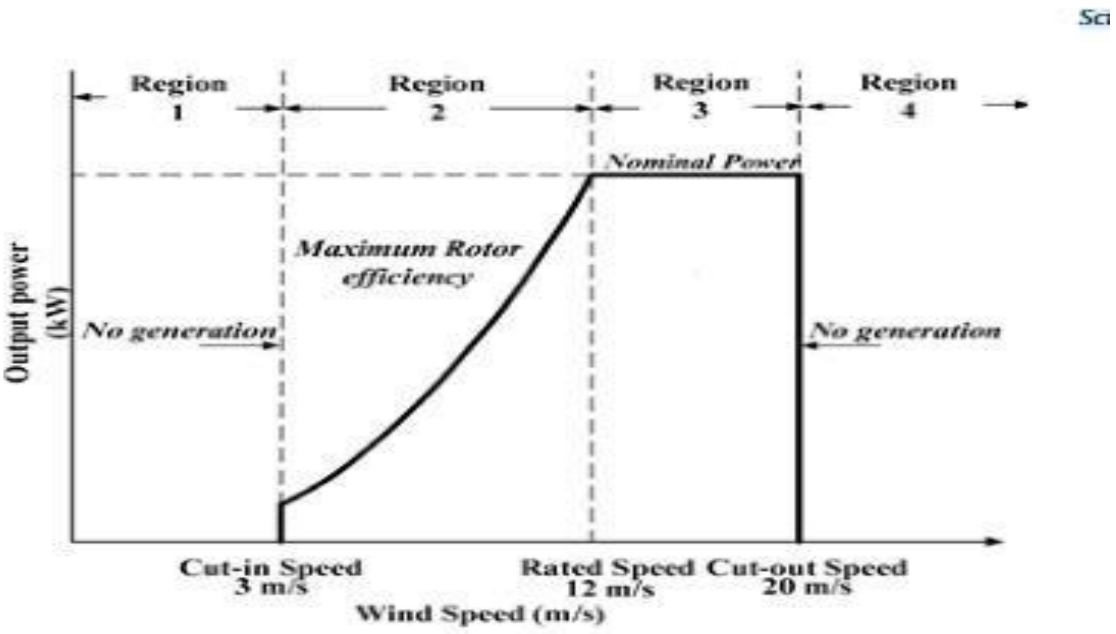

Figure 1.1 Wind Turbine working area

1.8.3 Wind Direction

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The word "wind power" refers to the conversion of wind energy into useful forms of energy, such as employing wind turbines to generate electrical power, windmills to generate "mechanical power," and wind pumps to pump or drain water.

The kinetic energy of moving air is known as wind energy.

During the time t, the total wind energy flowing through an imaginary area A is:[34]

$$\mathbf{E = \frac{1}{2} mv^2 = \frac{1}{2} Atv^3 \rho t} \qquad (1.1)$$

In an outside stream, wind power is proportional to the cube of the wind speed; when the wind speed doubles, the available power increases eightfold.As a result, wind turbines providing grid electricity must be extremely efficient at higher wind speeds.Because wind power is defined as energy per unit of time, the wind power incident on A is:[34]

$$P = \frac{E}{t} = \frac{1}{2} A\, pv^3 \rho \qquad (1.2)$$

1.8.5 Annual Energy Production (AEP)

The goal of any wind project is to supply energy, so an accurate estimate of production is important when planning a project.

CHAPTER TWO

2.1 REVIEW OF RELEVANT LITERATURE

In this section, we'll go through some of the most recent research publications on wind farm layout optimization and control systems.

Andrew Kusiak and Zhe Song presented "A multi-objective evolutionary strategy algorithm approach to the wind farm layout optimization problem" to solve the transformed bi-criteria optimization problem, which maximizes the expected energy output and economic function, which is related to turbine parameters and locations, as well as minimizes constraint violations (wind farm radius and turbine distance).

The disadvantage of this approach is that the wind energy calculation does not use the power curve function, which shows how large the turbine's electrical power production will be at various wind speeds. The optimization models did not completely consider wind direction.[35] Different terrains are not considered e.g., the terrain height information could be incorporated into the model. Furthermore, wind turbine constraint selection could be measured based on the wind farm wind features. For example, for a low wind speed area, there is no need to select large turbines with a high cut-in speed.[35]For the wind farm layout optimization challenge, Yunus Eroglu and Seckiner[2012] proposed an Ant Colony Algorithm. The algorithm was inspired by the way ants search for food and leave a pheromone trail to guide each other to food sources. The technique works with a set number of turbines that are randomly placed. Each turbine's pheromone quantity is determined by estimating the wake loss for that turbine, resulting in a stronger pheromone trail for turbines in poor locations. Because ants will follow the pheromone trail, more ants will try to improve the position of the bad turbines by moving them in random directions - the turbine will only be moved if the new position is better than the old. When the results are compared to those of [Kusiak and Song], it is clear that the ant colony method was successful in positioning two.[36] more turbines, eight turbines in total, and that when the number of turbines was greater than two, the ant colony algorithm produced more power, experienced less wake loss, and obtained higher efficiency. Wan et al. demonstrate how a Gaussian particle swarm algorithm can solve the wind farm layout optimization problem. Fish schooling, insect swarms, and bird flocking all serve as inspiration for swarm optimization. The given technique used an objective function that attempted to maximize produced power while minimizing constraint violations. The following is how the algorithm works:

To begin, particles (turbines) are randomly placed in (x, y)-positions. The original solution is calculated and the results are saved in the second step. Third, the population's best location is saved, together with each particle's current best position, which will be the first positions at first. An algorithm is provided for determining which of two layouts is the best. It works by prioritizing configurations that break fewer constraints first, and then comparing the power generated by the two layouts second. Then, for a specified number of iterations, an updating method is conducted. It first examines if the particle's local best position matches the global best position, and if it does, it employs a regeneration mechanism to relocate the particle to a random point. Otherwise, the particle's current position, current best-observed position, and global best-observed position, as well as two normalized random Gaussian numbers, are used to calculate a new position. The particle is shifted if the new position is better than the prior one. Each repetition includes a variance evolution local scheme to increase the algorithm's local search ability.

It operates by gathering three random particles as possible parents for a given particle at random and uniting them to create a new position that is assigned to the particle if it is better than the recent one. Results were showed that the power produced is higher using this algorithm. Their algorithm is also tested in a more realistic environment and compared against an empirical method as well as a simpler particle swarm algorithm. The results showed that the power generated was increased using the proposed algorithm. To overcome the wind farm layout optimization challenge, Martin Bilbao and Enrique Alba devised a simulated annealing approach. Simulated annealing (SA) is a comprehensive optimization met heuristic that aims to find a good estimate of the global solution.[37].The simulated annealing solver is implemented in the algorithm via the pseudo-code.SA There is only one uncertain solution. The preliminary solution is generated at random. A solution is perturbed in order to obtain a neighbour. The result is achieved by selecting and transferring the aero-generator from one spot to another. The new answer is saved if it is superior to the old one. If not, a chance governed by a lowering temperature parameter known as Boltzmann probability can be used.

Grady et al. employed the identical wind parameters and representation, and the algorithm was tested on the same three scenarios. The simulated annealing algorithm works as follows: First, an initial layout is obtained by randomly positioning a predefined number of turbines. Later, a random position that contains a turbine is chosen, and a new randomly generated location is suggested. If the new position is better, the turbine is moved, but if the new position is not better, the turbine is moved with a given probability which is regulated by a decreasing temperature parameter, to prevent the algorithm from converging to a local optimum. The simulated annealing algorithm was able to find solutions with better fitness, higher power production, higher efficiency, and significantly lower execution- and evaluation times, showing that simulation annealing might be a good technique to search for the optimal wind farm layout, and it should definitively be tested in a more realistic environment.

The drawback of this study is additional farm constraints were not considered, including actual factors, such as terrain effect and the impact of wind speed and wind direction.

Ju Feng and Wen Zhong Shen presented a Random Search algorithm for WF layout optimization based on continuous formulation in the fifth paper, and applied it to an ideal test issue in flat terrain. It was demonstrated that the RS method can get higher GA optimization outcomes. The algorithm starts with a conceivable layout and then iteratively evolves the layout in the feasible solution space based on the objective and restrictions.

When moving the WTs through the process, the old version of the RS algorithm randomly selects one WT and moves its location randomly at each "Random Move" step; however, this procedure has been improved by adding some adaptive tools, such as remembering and utilizing the information of a good move, which means a "Random Move" step that results in power increase.

It should be noted that the algorithm includes a "Feasibility Check" step that addresses the problem's restrictions, such as the WF boundary constraint and the least distance constraint Because the algorithm moves a WT at random in the "Random Move" phase, there is no guarantee that all of the constraints will be met for the new layout, hence this explicit feasibility check is required. Another feature worth mentioning is that the number of WTs in this approach is fixed, remaining the same as in the original configuration. This algorithm is straightforward, intuitive, and simple to implement.

It can be used as a last refining tool to improve the results of any other method, or as an optimization tool to optimize the architecture of a wind farm with a specific number of WTs. If the number of WTs is not specified, the layout optimization problem can be solved by running the RS algorithm multiple times with a different number of WTs at each time and then result the overall best layout. It's also worth noting that this method uses uncertainty to find better answers, and the process is terminated after a set number of evaluations. As a result, multiple runs for the same issue usually yield different solutions. As a result, it's common to have to run the algorithm numerous times to see how it performs. The main works that have been released to far are unquestionably a solid starting point for further study into more effective solution approaches, but they are insufficient for a variety of reasons. First, none of the provided solutions can evaluate the quality of the solution. To put it another way, none of the above works computes an upper bound on the power produced - except for the power produced if no wake effect is present. The algorithms planned in these works find a maybe good solution, but none of them can show how far it is from optimality. A wind farm designer requests to know this to decide if it is worth spending more time looking for a higher-quality layout. For the computation of wind speed and wake effects, the topography of the land is the second factor to consider. Existing works always take into account a flat area and presume that the wind distribution is uniform throughout the entire site.

The flat area statement is true for offshore sites, but not for onshore sites, where the topography is rarely level and uniform; the existence of hills, rivers, woods, roads, or buildings has a considerable impact on wind dispersion and wake behaviours yet, none of these factors have been explored.

Those limits will be taken into account in this project. Even if wake effects because of a decrease in wind speed, this is not their only negative consequence. Besides being slower, the air in the wake is also more windy, which, in the long run, may cause to blade harm and great repair costs. The existing approaches ignore this aspect But these optimization techniques could include the additional objective of minimizing the turbulence intensity besides the main objective of maximizing the power produced. Alternatively, a constraint may be included to prevent too large a value of turbulence intensity.

The next paper which is going to be revised is "Wind turbine pitch angle control using Fuzzy Logic Controller" by Parvathy Vijay an B [38]In this paper, a Fuzzy PID controller is used to control the pitch angle of a wind turbine. This controller was created using MATLAB ®'s Fuzzy Logic ToolboxTM.The controller was created using knowledge of the principles of operation for wind turbines with variable pitch angle control.

This does not necessitate the use of mathematical models. It is given as an alternative to the currently employed Proportional-Integral (PI) controllers. The system was not properly regulated in this work, since the informed simulation outputs were not good in terms of percentage overshoot and settling time. Finally, we discussed "Pitch Control for Variable Speed Wind Turbines" by A. I. Roussos, V. E. Ntampasi, and O. I. Kosmido.Using PID controllers, this research attempted to address some of the issues of wind energy control systems. The Ziegler – Nichols technique is used to create a PID controller. The suggested controller validates attaining a speedy convergence to the extracted power set point with the least amount of variations, even under extreme wind conditions, by properly setting the controller gains. However, when compared to FLC, the desired outputs are not as good.[39]

2.1 The significance of this paper in relation to the previouswork

The control technique of the system is one of the most significant features that is not discussed in the aforementioned studies. The turbine's impact on frequency and voltage stability is becoming increasingly significant. Aerodynamic loads, gravity loads, and centrifugal loads produce blade wear and shaking, resulting in rotor blade degradation. These stresses may be overcome, and the quantity of electricity collected can be managed, with the help of a proper pitch controller, which adjusts the attack angle of a wind turbine rotor blade into or out of the wind. Because the wind speed varies throughout the rotor blades, each blade is subjected to various loads. In this research, an adaptive fuzzy PID control pitch angle control system is developed to deal with the nonlinear features of turbines while also reducing the hundreds on the blades. Reduced blade loads will help to increase the wind turbine's performance, efficiency, and power output in the long run. In comparison to prior studies, the usefulness of the wind farm layout optimization method is discussed. The wake loss and the consequences of high wind speeds exceeding the rated speed of the Wind Turbines were discussed.

CHAPTER THREE

3.1 Construction of a Wind Farm

The steps of a wind park development project are briefly described in this section. The first stage is to create a windy location to confirm the project's economic viability. Landowners are contacted after a suitable site is identified and asked whether they are interested in hosting wind turbines on their property. Landowners who engage in the project typically receive a share of the profits generated by the turbines installed on their land, as well as additional funds if roads or other infrastructure is constructed on their land. However, contacting landowners and agreeing on lease conditions is a time-consuming process that normally takes a few months. Meanwhile, the wind developer erects measurement towers to evaluate the wind distribution (or wind rose) across the entire site.[1] The characteristics of a turbine that are associated with wind park layout optimization are the following:

- Cut-out speed co
- Nominal (rated) speed
- Nominal(rated) power
- Power curve
- Thrust coefficient curve
- Rotor diameter d
- Hub height z
- Cut-in speed ci

The blades of the turbine start spinning when the wind speed exceeds ci, and the turbine creates power. The facility produced roughly increases with the cube of the wind speed until the wind speed hits the nominal speed, at which point the turbine's system changes the pitch of the blades to maintain a constant facility produced.

3.2.1 Wake Model

The Jensen model, the Ainslie model, the Larsen model, and hence the Lissaman model have all been created to assume wake. Analytical wake models are better appropriate for treating wind park layout optimization, according to published publications. As a result, this research confirms that the Jensen wake model is the best qualified in terms of simplicity, estimating performance, and computation time. As a result, this model will be used to anticipate wind velocity deficits in the downstream area during this project. Jensen also assumed that the wake enlarges linearly as the distance downstream increases.Jensen's analytical wake model is used to investigate the wake effects between the turbines. He examined a closed-form wake region that expands linearly, resulting in a reduction in wind velocity that decreases linearly inside the wind flow direction.[19]

Wake model

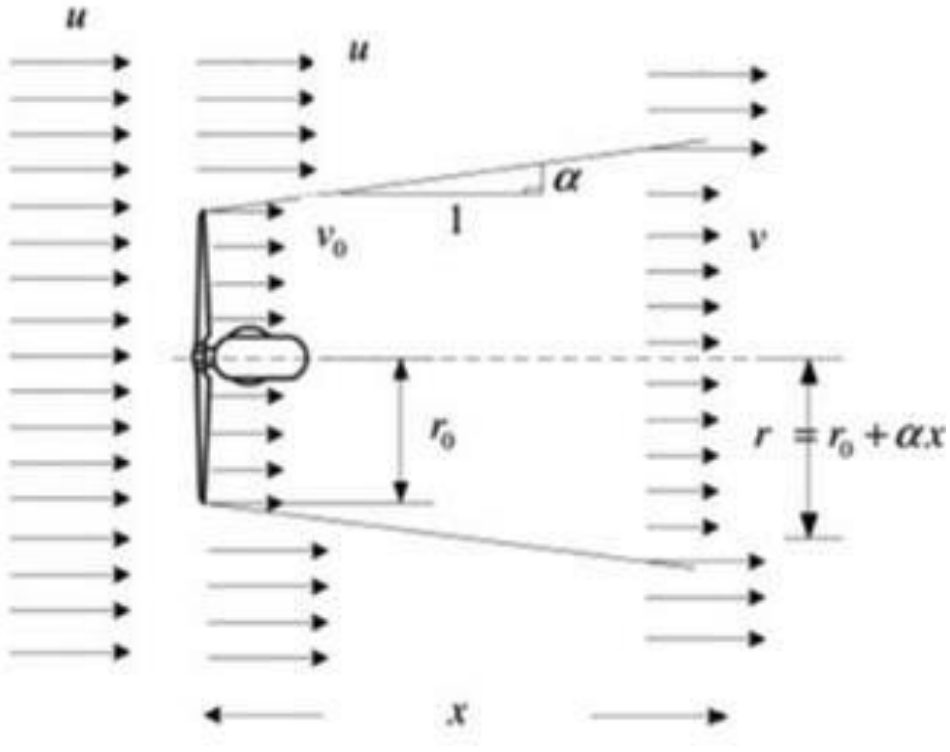


Figure 3.1 Wake from a single wind turbine

The velocity *u* , in the wake at downstream distance, *x* , from the wind turbine is[32]

$$U = u_0[1-2a(1 + \frac{\alpha x}{rd})^2] \qquad (3.1)$$

where, u_0, is the wind velocity unaffected from any wind turbine or free stream velocity. *a* , is theaxial induction factor and is calculated from the thrust coefficient, CT of the turbine . because the wind approaches the turbine , it slows down. The ratio of this reduction and therefore the free stream velocity is named the axial induction factor value should be 0.5.

The wake radius immediately upstream of the turbine is adequate to the turbine rotor radius but because the energy is extracted from the wind across the width of the blade, the wake expands. The wake radius immediately downstream of the turbine is named downstream rotor radius of the turbine ,$r_{d,}$ and is computed using[32]

$$r = r_0\sqrt{\frac{1-a}{1-2a}} \qquad (3.2)$$

the radius of the downstream wake is expanded linearly with the distance as

$$r = r_0 + a \qquad (3.3)$$

α is called entrainment constant(wake decay constant) and signifies how fast or slow wakeexpands.[32]

$$\alpha = \frac{0.5}{\log(\frac{z}{z0})} \qquad (3.4)$$

Here, z_0 is the surface roughness height of the site *and z* is the hub height of the wind turbine,

For cases where a wind turbine encounters multiple wakes from numerous upstream windturbines, the Jensen model is extended as follows .combination of wakes.[32]

$$(\mathbf{1}-\frac{u}{u0})^{2}=\sum_{i=1}^{Nt}(\mathbf{1}-\frac{u}{u0})^{2} \quad (3.5)$$

$(\mathbf{1}-\frac{u}{u0})^{2}$, is Wind speed deficit

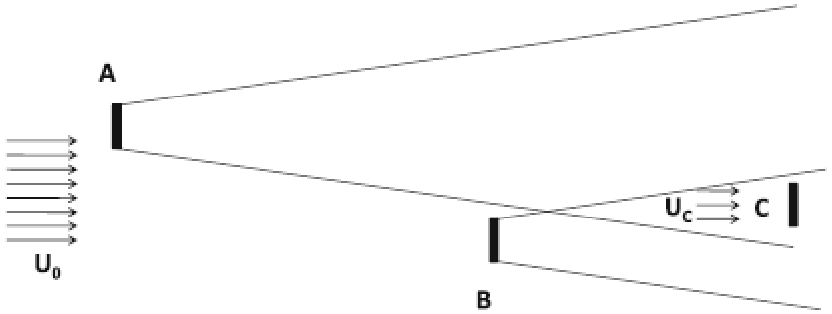


Figure 3.2 multiple wakes affecting a position[32]

3.2.1.1 Topography

The topography of the earth is the variability or irregularity in elevation(high or low) within a sampled terrain unit. The specific physical of land is a terrain like rivers, cities, hills, mountains. In this study, the flat terrain is considered by the surface roughness characteristic value is equal to 0.03m.

3.2.1 Cost Model

The following model is chosen to determine the cost of the wind farm, it was also used in previous studies.[32]

$$\text{Cost}=\boldsymbol{N}[\frac{2}{3}+\frac{1}{3}\boldsymbol{e}^{-0.00174N^{2}}) \quad (3.6)$$

where, Nt is the number of wind turbines purchased.

3.2.2 Power Calculation

Power produced from the wind farm which is dependent on the number of wind turbines andtheir placement. Available power in wind is given by,[32]

Available power = $\frac{1}{2}$ pAu^2 (3.7)

The power generated from a wind turbine is.

$P_{\mathrm{WT}} = \frac{1}{2}\mathrm{C}\,(\lambda, \beta)\mathrm{p}Au^3$ (3.8)

Where

p is the air density (typically 1.225 kg/m3),

A is the rotor blades area (in m2);u is the wind speed (in m/s), and

Cp**(λ, β)** is the power coefficient (has no dimension).β is WT pitch angle (in degree),

$\lambda = w_m R/u$ tip speed ratio

$w_m =$ turbine rotor speed(rad/sec)R = rotor radius

The turbine power coefficient, Cp(,), is the ratio between the mechanical power available at the turbine shaft and the power available in the wind, and it describes the power extraction efficiency of the wind turbine. When it comes to wind speed, Cp is quite non-linear. The output power will grow as the wind speed increases. As a result, a control system is required to maintain the output power within the specified parameters. This is accomplished by altering the blade angle, which alters the power coefficient and, as a result, the output power. The following equation is used to model Cp(,) based on the modeling turbine characteristics.

$$\mathrm{Cp}(\lambda,\beta)=0.5176(116*\frac{1}{\lambda i} -0.4\beta- 5)e^{-\frac{21}{\lambda i}}+0.0068\lambda \qquad (3.9)$$

$$\frac{1}{\lambda i} = \frac{1}{\lambda+ 0.08\beta} - \frac{10.035}{1+\beta^3} \qquad (3.10$$

λi is an intermediate variable used to facilitate calculations.

Cp is a nonlinear function of λ and blade pitch angle β

$$\lambda=w_m R/u \qquad (3.11)$$

Thus, the power coefficient will modify the quantity of power found from the wind. According to equation (3.9) by changing β, the power coefficient Cp is changed. Wind turbine power regulator is based on this principle.

The total power generated by WTs operating under wake effect is [29]

$$\text{PWF(total)} = \sum_{i=1}^{Nt} PWT \quad = \sum_{i=1}^{Nt} \frac{1}{2} \text{C p}(\lambda, \beta)\rho \text{Au3} \qquad (3.12)$$

3.2.3 Theoretical Limit of Wind Energy Extraction

In 1919, German physicist Albert Betz investigated the relationship between a wind turbine's input and output wind velocity. He proposed Betz's Law, a theoretical limit for wind energy extraction for each given wind turbine of 16/27 or 59.3 percent of the kinetic energy in the wind inflow for any particular wind turbine. There is currently no wind turbine that can harvest electricity at such rate. Modern wind turbines can only attain 75 to 80 percent of the Betz limit. Nonetheless, in the suggested technique, the Betz coefficient is employed as a continuous in the calculation of total wind power.

The equation for total wind power for a single wind turbine, according to Betz's Law, is [29].

$$\text{P} = 0.593^{*} \frac{1}{2} \text{p} Au^{2} \qquad (3.13)$$

3.2.4 Efficiency calculation.

For calculating the Efficiency from the wind farm, wake losses due to wake of the upstreamwind turbines must be taken into account by Eq. (3.14) and the objective function Eq. (3.15) [29]

$$\text{Efficiency} = \sum_{i=1}^{N} \frac{\frac{1}{2}\text{C p}(\lambda,\beta)\rho\text{Aui3}}{\text{N}\frac{1}{2}\text{C p}(\lambda,\beta)\rho\text{Au3}} \qquad (3.14)$$

$$\textbf{Objective function=minimize}\left(\frac{\textbf{cost}}{\textbf{total power produced}}\right) \qquad (3.15)$$

CHAPTER FOUR

4.1 Optimization Methodology

4.1.1 Concept of Genetic Algorithms

A genetic algorithm is an evolutionary algorithm, or more precisely, a guided random search strategy, that is widely used to evaluate huge search spaces and find the best feasible solutions to problems. It is based on Darwin's Theory of Evolution and essentially comprises of the natural approaches for solving a combinatory problem stated below:

I. Fitness
II. Selection
III. Crossover
IV. Mutation

A chromosome containing many genes containing the problem-relevant information encodes a possible solution to a problem. A population is defined as the entire set of chromosomes, or people, and a generation is defined as the population of a specific iteration. A fitness function calculates an objective value for each individual that measures the efficiency with which the individual solves the given challenge. To avoid the algorithm becoming stuck in local optima, a subset of all the people is chosen, with "good" or "fit" parents and an acceptable number of "bad" parents available.

Parents produce new children using a crossover procedure that divides their genetic code into numerous bits and then reassembles it so that the offspring have genetic information from both parents. A low mutation rate randomly converts the genetic information to take into explanation possible random changes. The general sequence of a genetic algorithm for a given problem is as follows [25]

1. Create an initial population with a certain amount of individuals

2. Evaluate the fitness value of all individuals

3. Select parents based on their fitness value

4. Recombine their genetic code through crossover

5. Mutate a certain amount of genes to avoid premature convergence

6. Go to step 2 until a stop criterion is met

Genetic Algorithms are employed to solve the problems in this thesis (GAs).

GAs maintain track of a population of solutions that evolves over time as a result of combinations and selections. Solutions are joined at each iteration, yielding a new solution with components inherited from one of two parents. Each of the 100 binary variables xi (with I = 1,...100) in a solution indicates the presence of a turbine in position i.As a result, effectively merging two solutions entails developing a new solution with some turbines in the first parent's places and others in the second parent's positions.

Some of the components of a new solution may be changed after it is created in order to introduce variation into the population. Because of its similarities to the genetic changes that occur during species evolution, this mechanism is known as mutation.According to a computer study, GA-generated solutions had a greater objective function value and efficiency than solutions generated by randomly placing turbines.[28] defines efficiency as the ratio between the total energy extracted by a wind farm with N turbines and N times the energy extracted by an isolated turbine, which is a typical technique of evaluating and comparing solutions.[25] Optimization problem of Wind Farm design layout requires the design variables, the constraints, the objective function and optimization method.

Design variables: They consist of input parameters that can be varied to find the optimumsolution.

Constraints: Describe the variation fields of design variables.

Objective function: It is the criteria to be optimized the aim of this study is to maximize the power production of WF by reducing the wake effect.

Optimization method: The nature of the optimization problem has a big impact on this.

Because of the non-linear nature of power generation, it must be assessed using a variety of criteria.

Trial and error or deterministic methods cannot be used to optimize WF design.

Evolutionary algorithms are commonly utilized as a result of this.

This study's optimization steps include the use of a genetic algorithm (GA). Any optimization problem including Wind Farm design layout requires the definition of four essential elements: the design variables, the constraints, the objective function and optimization method. The formulation of these elements in the context of WF design layout is explained in subsections.

i) Design variables***:*** consist of input parameters that can be varied to find the optimum solution. In our optimization study, consider these design variables: position of each N(*x*, *y*), for N Wind Turbines.

ii) Constraints:

They describe the design variable variation fields, implying that due to the established constraints, all solutions are not viable.Wind turbines cannot be built beyond the wind farm territory because the size of the wind farm is limited.The maximum inter-space required between two WTs is defined by the basic limitations that are respected throughout the optimization of WF layout.The minimum distance between any two turbines is 5D, which is assumed in our study to be five times the rotor diameter and may be stated by the following equation.The diameter of a wind turbine is D.It is possible to state the minimum distance constraints [25].

$$d_{ij}=\sqrt{(x\mathrm{i}^2-x\mathrm{j}^2)+(y\mathrm{i}^2-y\mathrm{j}^2)\geq 5D} \quad \text{for i,j} = 1,2,\ldots N, \qquad (4.1)$$

iii) Objective function The objective function is the standards to be optimized (maximized or minimized).the main aim is to maximize the power production of WF .To optimize the cost per unit power (objective function) for a wind farm, the total cost of the wind farm is to be determined and the total power generated is to be calculated. This study addresses the problem of multiple objectives by joining it into a single formulation. The standards to be optimized are the objective function (maximized or minimized).The primary goal is to increase WF's power output.

The overall cost of a wind farm must be minimized in order to optimize the cost per unit of power (objective function).The entire power generated must be determined and computed.

The difficulty of various objectives is addressed in this work by combining them into a single statement.

iv) Optimization method Itis strongly dependent on the nature of optimization problem.

It is commonly understood that, because to the non-linear nature of power generation, it must be evaluated using a variety of variables. Traditional approaches, such as trial and error or deterministic algorithms, cannot handle WF design optimization. As a result, evolutionary algorithms are widely employed in genetic algorithms (GA). Its ability to tackle complex and non-linear issues will be justified.As a result, we're interested in using this way of optimization, which is based on a continuous planning approach in which WTs can be placed anywhere within the Wind Farm area, in our research.

[24]

4.1.2 Optimization Process

In MATLAB, a code is written to calculate the electricity generated and the cost of a wind farm.For optimization, the code is combined with the genetic algorithm solver, "genetic algorithm solver, included in MATLAB's genetic algorithm toolbox."The "genetic algorithm solver" is a single-objective function genetic algorithm solver (equation 3.15).[16]

CHAPTER FIVE

5.1 Pitch Control Mechanism

The electronic controller of a pitch-controlled turbine orders the turbine's output multiple times each second.

When the wind speed exceeds the rated value, the pitch controller reduces the angle of attack, gradually turning the blades out of the wind (pitching).

As a result, the rotor blades must be able to rotate around their longitudinal axis (to pitch).

The best operating conditions of a pitch-controlled 2 MW wind turbine are shown in Fig.5.1.2.

The blades will pitch a fraction of a degree at a time during normal operation, and the rotor will turn at the same time. When the wind changes, the controller will normally pitch the blades a few degrees to keep the rotor blades at the optimal angle to maximize output power at all wind speeds.

[15] The power coefficient measures a wind turbine's efficiency (Cp). Ideally, the power coefficient is determined as the ratio of the rotor blade's mechanical power to the wind's power. We can change Cp by adjusting the pitch angle and tip speed ratio.The equation contains the calculation for this case.The coefficients c1–c6 and x in the equation are those that wind turbine manufacturers should supply.The greatest power coefficient that any turbine may achieve is 0.59, which is known as the Betz limit.[34]

$$Cp(\lambda,\beta) = c_1[c_2\frac{1}{\Lambda} - c_3\,\beta - c_4\,\beta^{x} - c_5]e^{(-c_6\frac{1}{\Lambda})} \qquad \text{(i)}$$

$$\frac{1}{\Lambda} = \frac{1}{\lambda+0.08\,\beta} - \frac{0.035}{1+\beta 3} \qquad \text{(ii)}$$

$$P = \frac{1}{2}\,Cpv^{3}\rho\,(\lambda,\beta)$$

$\lambda = \omega R/v$

where P output power

ω blade angular velocity

v wind speed

R blade radius

β Pitch angle

λ Tip speed ratio

ρ wind density (1.225kg/m3)

According to the above equations, I have tried to show the effect of pitch angle on the output power by plotting on MATLAB

Cutin speed 3m/s,Rated speed is 12m/s ,Cut off speed is 25m/s ,Prated = 2MW

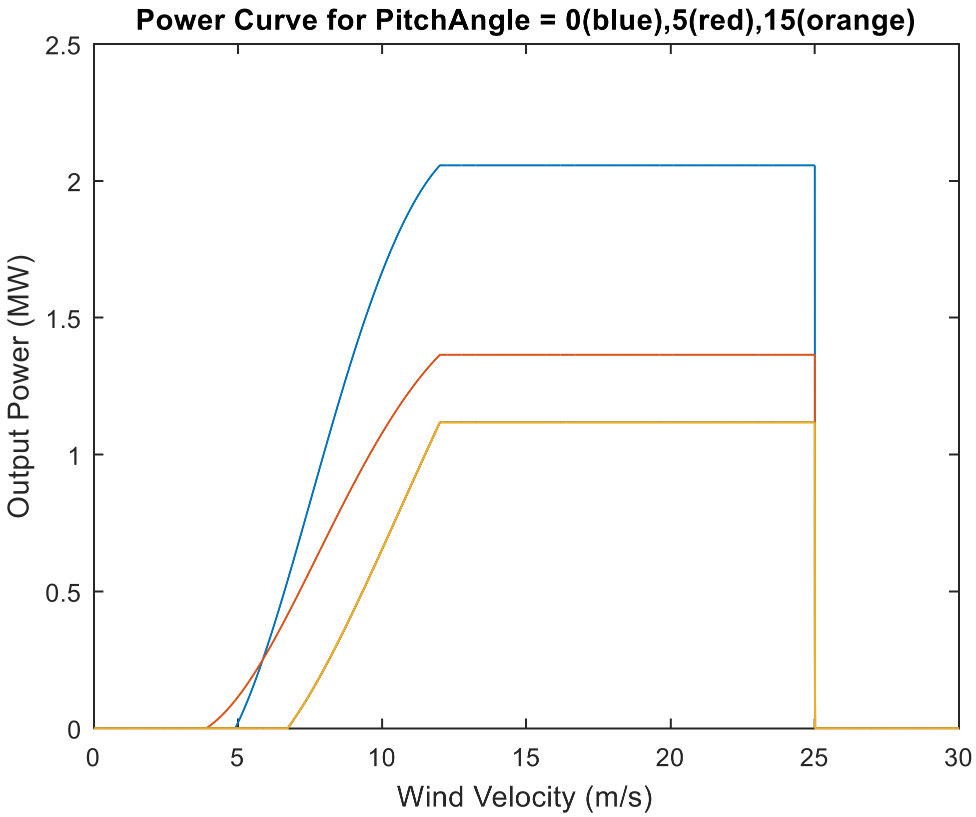
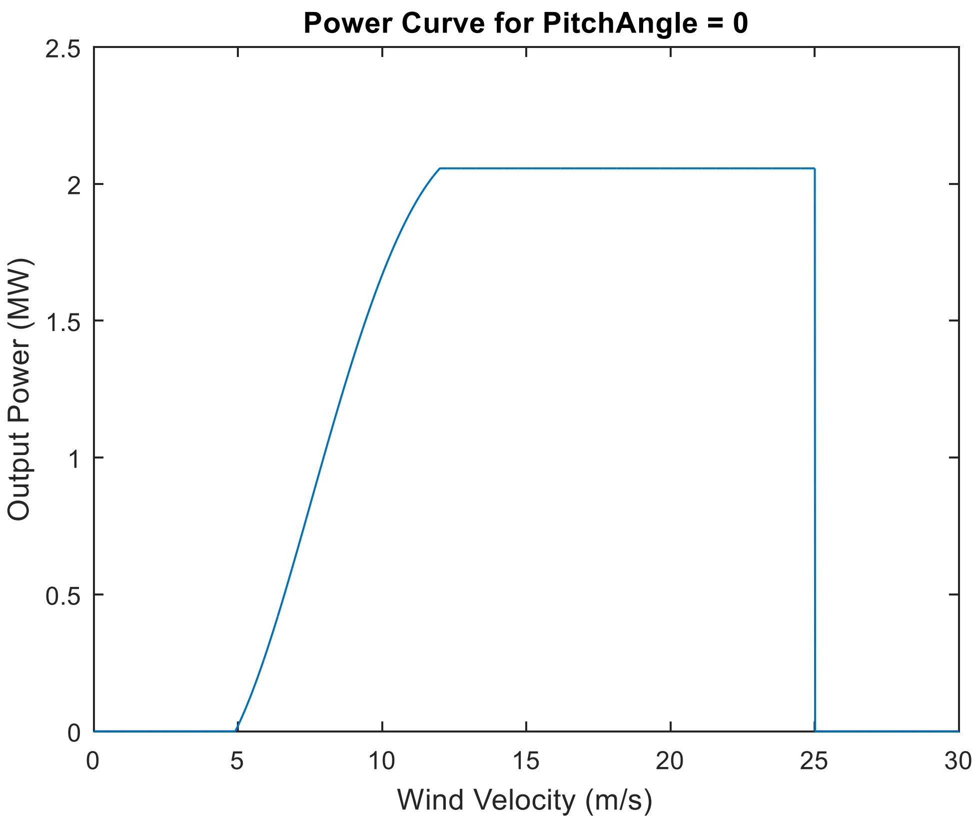


Fig 5.1.1 Consequence of the pitch angle on the output power

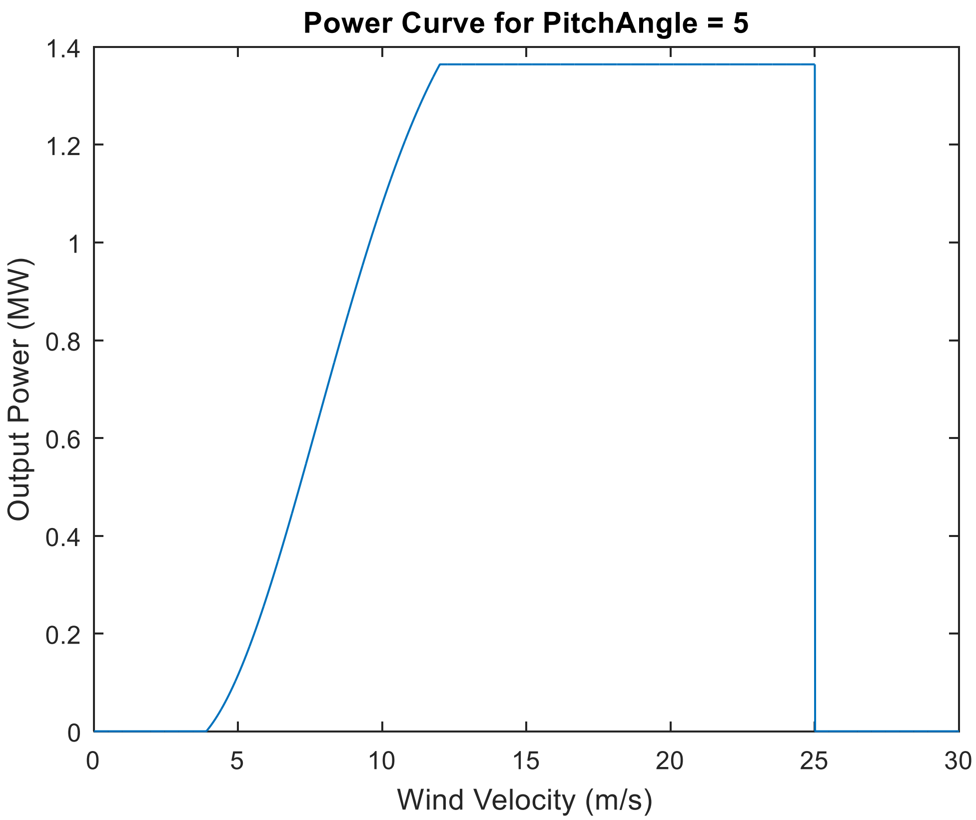


5.1.1 (a) Effect of the pitch angle(0 deg) on the output power

i) For Pitch angle = 0 deg, the following outputs are obtained

Cp = 0.25

P(output power) = 2.0567MW

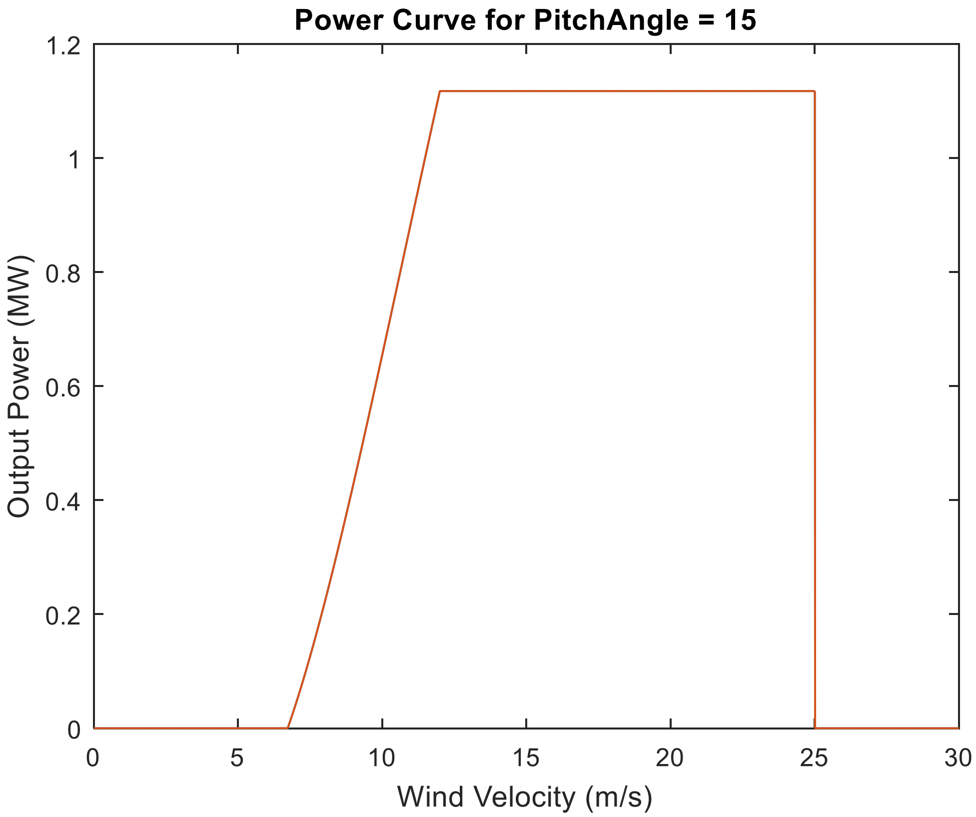


5.1.1 (b)Effect of the pitch angle(5deg) on the output power

ii) For Pitch angle = 5deg, the following outputs are obtained

Cp = 0.1614

P(output power) = 1.13456MW



5.1.1 (c) Effect of the pitch angle(15 deg) on the output power

i) For Pitch angle = 15 deg, the following outputs are obtained

Cp = 0.1344

P(output power) = 1.1175MW

These graphs show how the output power increases when the pitch angle varies(output power is maximum at zero pitch angle). Hence for optimal performance of a wind turbine, controlling the pitch angle is required.

5.1.1 Modeling of the Wind Turbine System

The graphic below [12] shows a block schematic of a typical wind turbine scheme concept.The pitch actuator model and the driving terrain model are detailed in the next sections

.

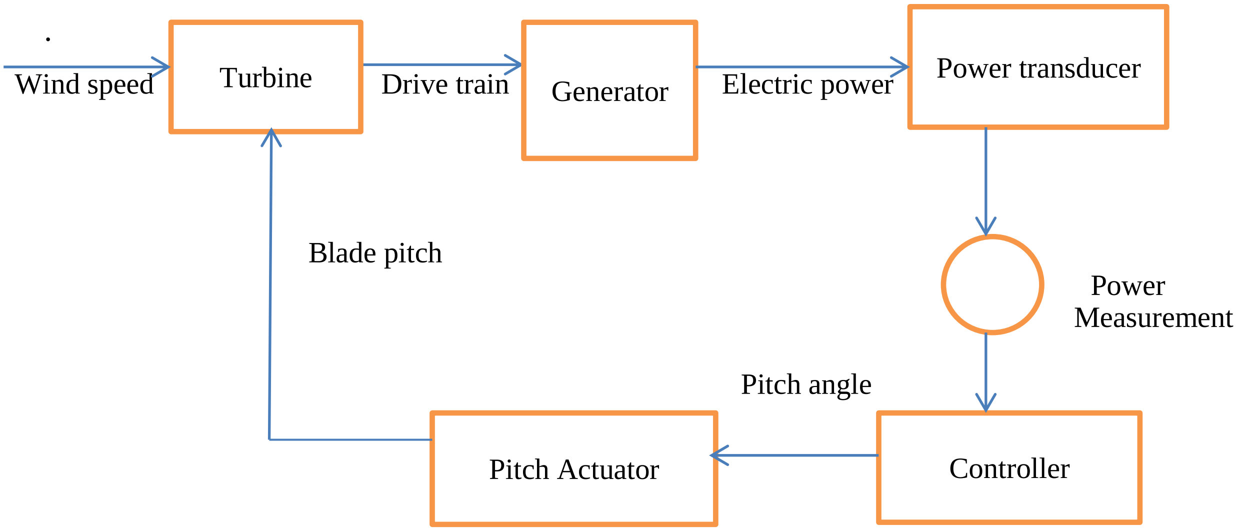


Figure 5.1.2 Wind Turbine System Feedback Control System Model[12]

5.1.2 Pitch Actuator Model

The pitch actuator rotates blades parallel to their longitudinal axis.The actuator model describes the dynamic behavior of a pitch demand from the pitch controller and pitch angle measurement [12]. The pitch angle change is provided by

$$d\beta/dt = (\beta d - \beta)/T_\beta \qquad (5.1)$$

$$\beta/\beta d = 1/(sT_\beta + 1) \qquad (5.2)$$

$$T_\beta . d\beta/dt = (\beta d - \beta) \qquad (5.3)$$

$$T_\beta . d\beta/dt + \beta = \beta d \qquad (5.4)$$

$$T_\beta . \beta s + \beta = \beta d \qquad (5.5)$$

This is the required Transfer Function. The value of time constant of pitch actuator, T p can becalculated from initial parameters of Wind Turbine [20] shown in Table 4.1.

Rated generated power,Pe	1500KW
Rated generator peed ,Wg	1500rpm
Rated tuning speed of rotor,Wt	20 rpm
Wind turbine blade radius ,R	35m
Reference pitch angle , □d	0 to 90 deg
Rate of change of pitch angle	0.6 deg/sec
Control accuracy of pitch angle	0.3 deg
Damping coefficient ,B	2 N.m/rad/sec
Drive-train inertia, Jt	0.75N.m2

Table 5.1.1 parameters of Wind Turbine

$$T\beta = (\beta d- \beta)/(d\beta/dt) = 0.3/0.6=0.5 \quad (5.6)$$

$$\beta/\beta d = 1/(0.5s+1) \quad (5.7)$$

5.1.3 Drive Terrain Model

The figure below shows the drive terrain model.

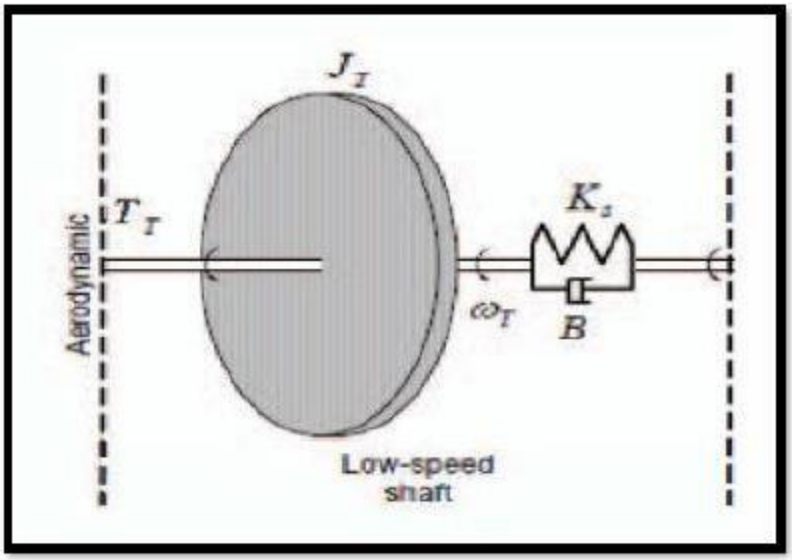
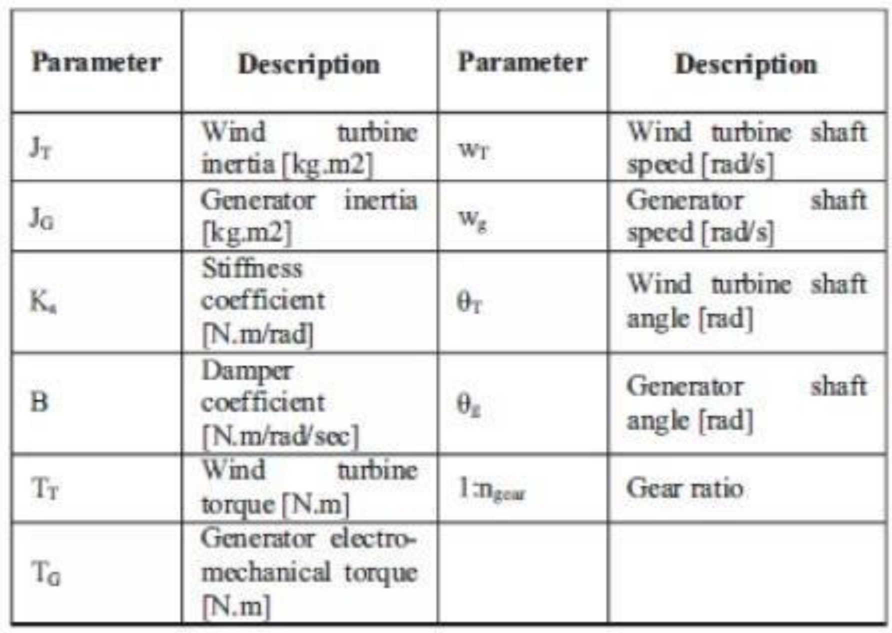


Figure 5.1.3 Mechanical model of drive train

The parameters taken while modeling the drive train are shown in Table 5.1.2



Parameter	Description	Parameter	Description
J_T	Wind turbine inertia [kg.m2]	w_T	Wind turbine shaft speed [rad/s]
J_G	Generator inertia [kg.m2]	w_g	Generator shaft speed [rad/s]
K_s	Stiffness coefficient [N.m/rad]	θ_T	Wind turbine shaft angle [rad]
B	Damper coefficient [N.m/rad/sec]	θ_g	Generator shaft angle [rad]
T_T	Wind turbine torque [N.m]	$1{:}n_{gear}$	Gear ratio
T_G	Generator electro-mechanical torque [N.m]		

Table 5.1.2 Mechanical Model Parameters of Drive Train[12]

The dynamics of drive-train are described by following differential equations: [12]

$J_T d/dt(w_T) = T_T-(ks\delta\boldsymbol{\theta_T}+\mathbf{B}\delta\mathbf{w})$ (5.8)

$d/dt(\delta\boldsymbol{\theta_T}) = \delta\mathbf{w}$ (5.9)

Then by using Newton's second law of motion, we get

$Jdw/dt = T-Bw$ (5.10)

Applying Laplace transform on both sides

$J_T d/dt(w_T) = T_T-(ks\delta\boldsymbol{\theta_T}+\mathbf{B}\delta\mathbf{w})$ (5.11)

$JWs = T-BW$ (5.12)

$JWs+BW=T$ (5.13)

$W(JS+B)=T$ (5.14)

$W/T=1/(Js+B)$ (5.15)

This is the required first order Transfer function of Drivetrain. This can also be represented as

$W/T=(1/B)/((J/B).s+1$ (5.16)

$W/T=(1/2)/((0.75/2)S+1=0.5/(0.375S+1)$ (5.17)

Thus, the mathematical model of wind turbine is derived.

5.2 Controller Design

The traditional PID controller is a linear controller that uses the proportion (P), integration (I), and differential (D) of the deviation as input variables to generate the output acting on the regulated target (T). Figure 5.2 depicts the principles [31]

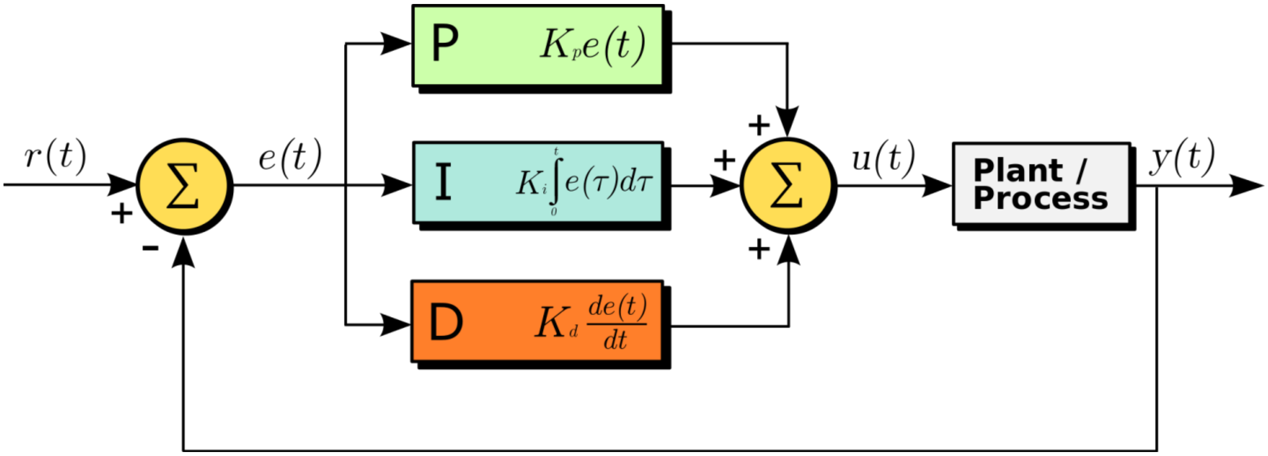


Figure 5.2.1Principle Diagram of PID Controller[20]

The output of a PID controller, equal to the control input to the plant, in the time-domain is asfollows:

$u(t) = K_pe(t)+Ki\int_0^t e(T)\quad dT + Kd\ d/dt\ e(t)$ (2.2.1)

Kp= Proportional gain; Ki = Integral gain; Kd= Derivative gain

PID controller works in a closed-loop system using the diagram shown below [20].

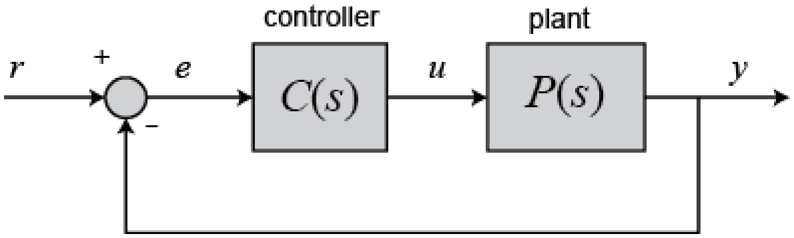


Figure 5.2.2 Unity Feedback System[7]

The tracking error, or the difference between the specified input value (r) and the actual output (y) from the controlled target, is represented by the variable (e). This error signal (e) will be passed to the PID controller, which will compute both the derivative and integral of the error signal. The proportional gain (Kp) times the magnitude of the error plus the integral gain (Ki) times the integral of the error plus the derivative gain (Kd) times the derivative of the error equals the control signal (u) to the plant [7]. The plant receives this control signal (u), and the new output (y) is obtained. The new output (y) is then fed back and compared to the reference to find the new error signal (e). The controller then computes the derivative and integral of this new error signal indefinitely [7]. The Laplace transform is used to determine the transfer function of a PID controller. A proportional controller (Kp) reduces the rise time and can reduce the steady-state error, but never completely eliminates it [7]. For a constant or step input, an integral control (ki) will eliminate the steady-state inaccuracy, but it will make the transient response slower and cause oscillations. The effect of a derivative control (kd) is to improve the system's stability, reduce overshoot, and improve the transient response.

5.2.1.1Tuning of the PID Parameters

This section describes one among the several methods for tuning controller parameters in PID controllers, that is, methods for locating proper values of Kp, Ki, and Kd. the most aim of tuning the parameter is to realize faster response and good stability (low oscillations) of the plant system

5.2.1 Fuzzy Control

The most active study topic in the application of fuzzy set theory, fuzzy reasoning, and fuzzy logic is fuzzy logic control (FLC).

A control system is a set of physical components that are used to change the behavior of another physical system so that it shows certain desirable characteristics. The mode of human language can be used to express fuzzy logic. The linguistic variables are diverted to an automatic control scheme using an FLC.A knowledge database constructs fuzzy logic rules [20]. Set the input variables for the FLC to be error (e) and change of error (e), and output 1 to be the output variable. Fuzzy control theory is an artificial control paradigm based on fuzzy set theory, the representation and reasoning of fuzzy linguistic knowledge, and fuzzy logic rules to replicate human thinking and reasoning.

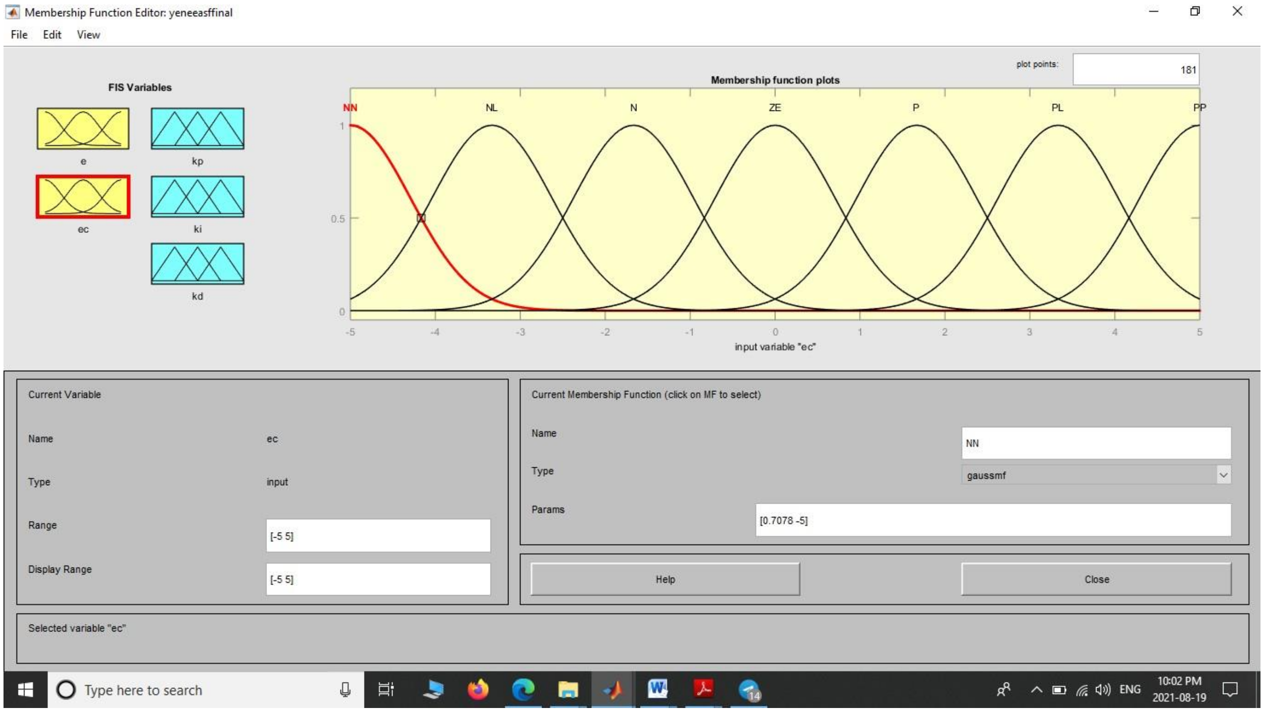
The fuzzy logic controller design includes fuzzification, rule base, inference, and defuzzification. The most practical method for controlling blade pitch angle is to employ rule-based fuzzy logic controllers. Because fuzzy logic is good at dealing with uncertainty, such controllers are particularly suited for situations where system parameters are unknown or have a fluctuating tendency from their predicted value. The parameter wind speed is a fluctuating quantity in the case of wind turbines. The major benefit of fuzzy logic is that it does not necessitate a precise model description. Fuzzification, rule base, inference, and defuzzification are all part of the fuzzy logic controller architecture.MATLAB/Simulink is used to create this controller.

[9]

Fuzzification

The fuzzy controller's inputs and outputs are defined in this step. This application has two inputs (error and alter in error) and three outputs (Kp, Ki, Kd). The three parameters of the PID controller are automatically updated to support the error (e) and change in error (ec) [11].For all inputs and outputs, we've chosen Gaussian membership functions. The variable universe of discourse for the system pitch error e and thus the change in error "ec" is taken as -5, -4, -3, -2, -1,0, I, 2,3,4, 5 and then divided into seven levels, the linguistic values of the seven fuzzy sets. were taken as {NN, NL, N, ZE, P, PL, PP}, that's { Negative Negative, Negative Large, Negative, Zero, Positive, Positive Large, Positive Positive }. The input error ‘e’ and output ‘Kp’ with gaussian membership functions are shown within the figures below.

The input variables of FLC is chosen as gauss waveform so as to coverage all points within the domains as shown within the figure below.



Current Variable

Name: ec

Type: input

Range: [-5 5]

Display Range: [-5 5]

Current Membership Function (click on MF to select)

Name: NN

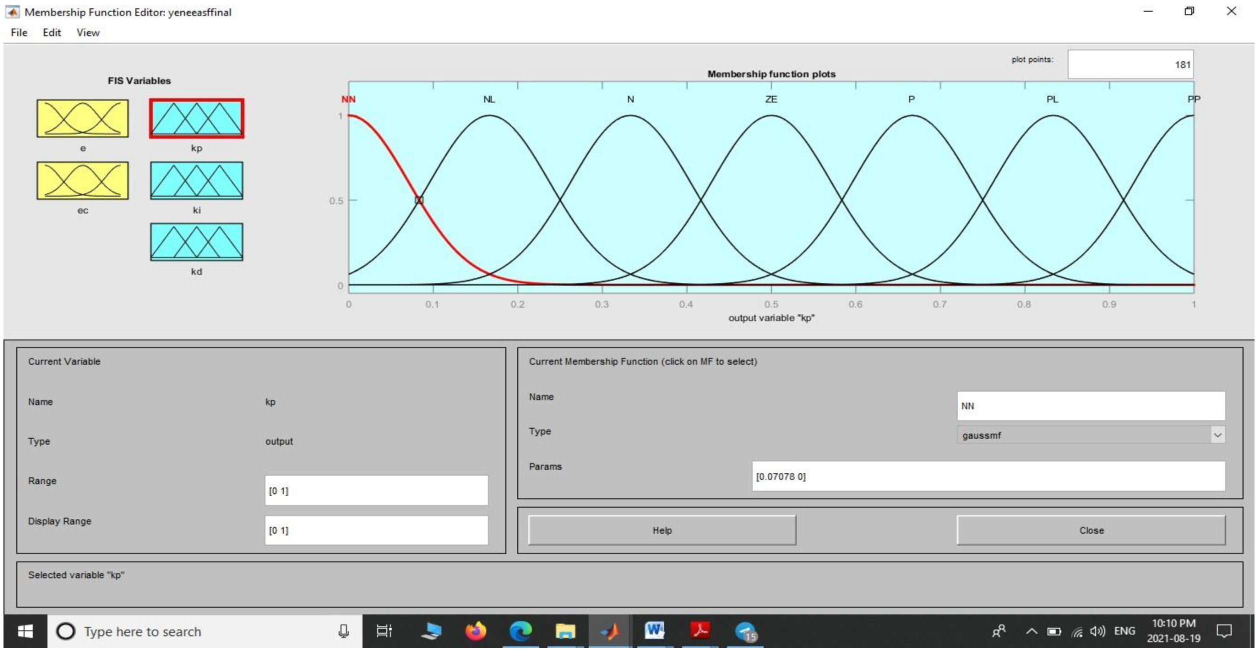
Type: gaussmf

Params: [0.7078 -5]

Selected variable "ec"

Figure 5.3.1 Membership Function Plots for Input ce

.



Current Variable

Name: kp

Type: output

Range: [0 1]

Display Range: [0 1]

Current Membership Function (click on MF to select)

Name: NN

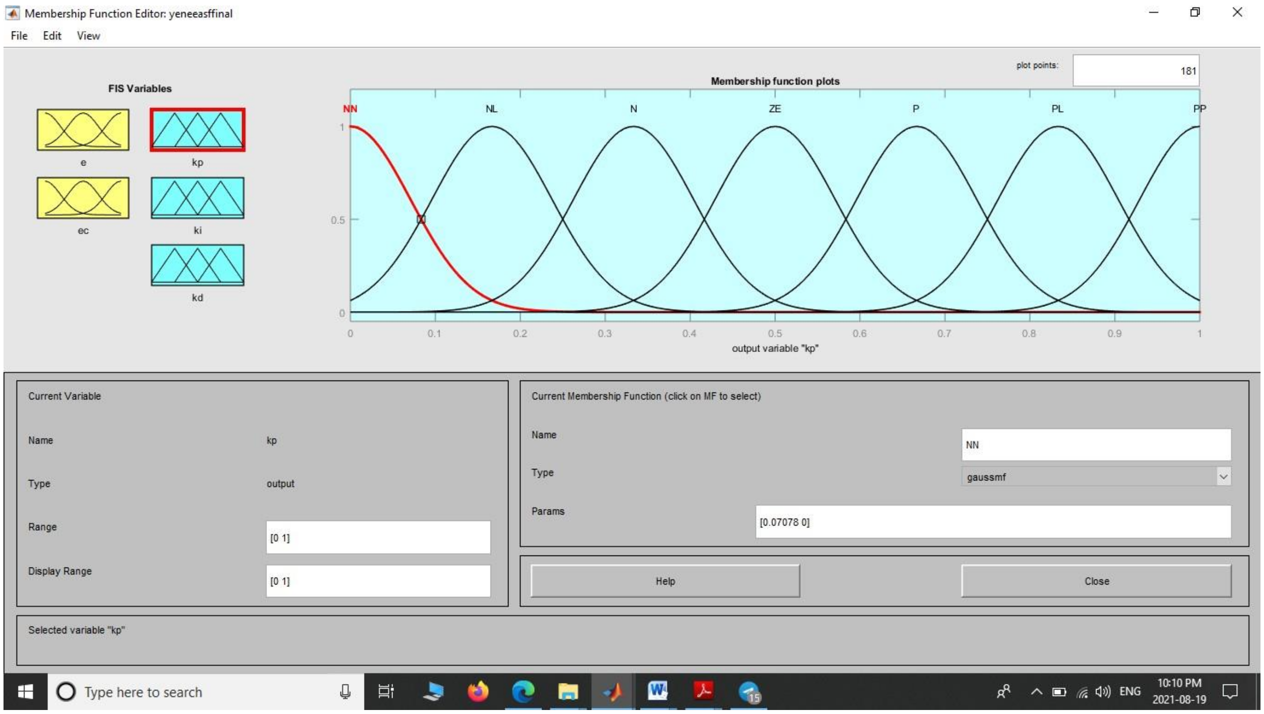
Type: gaussmf

Params: [0.07078 0]

Selected variable "kp"

Figure 5.3.2 Membership Function Plots for Input kp

The output variable is selected as trams waveform in order to keep the output signal lies withinlinear region .



plot points: 181

Name: kp
Type: output
Range: [0 1]
Display Range: [0 1]

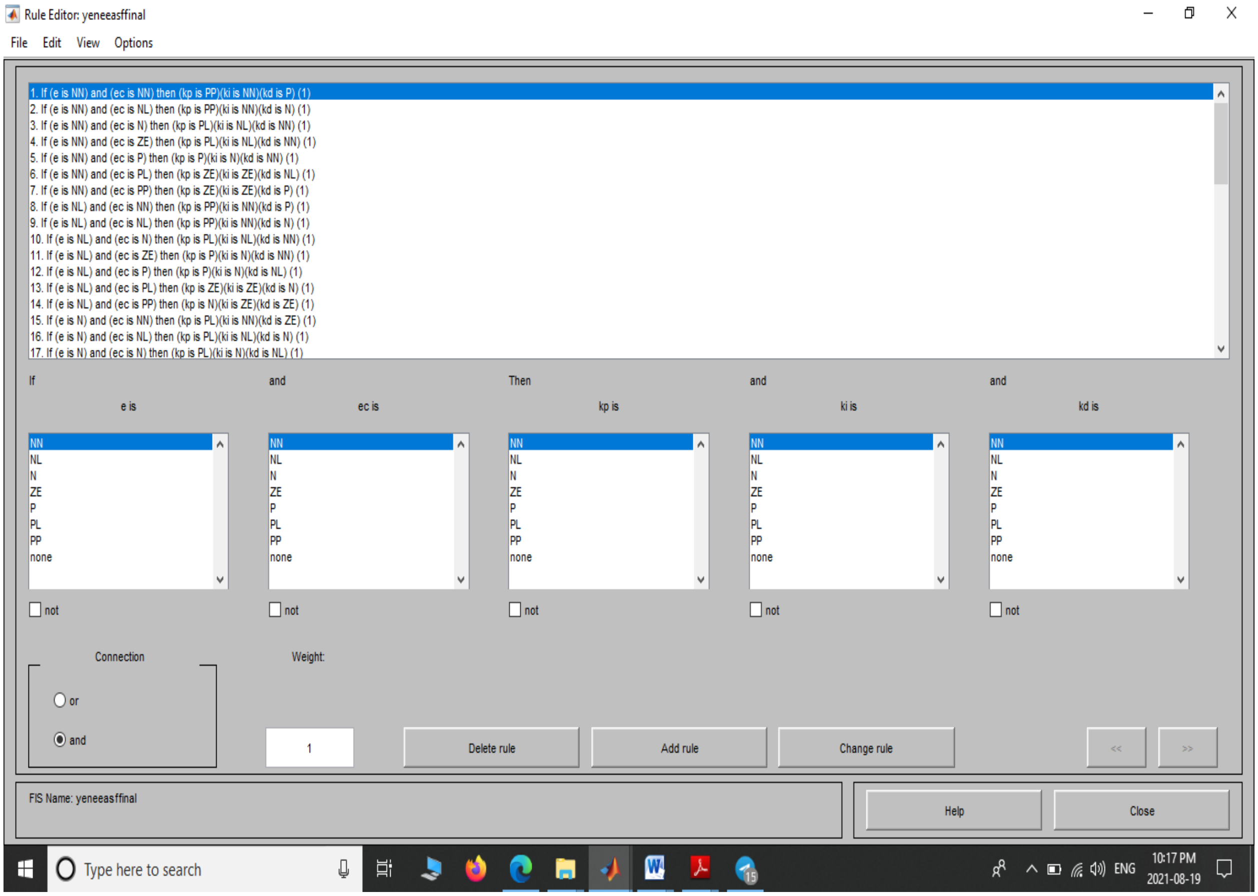
Name: NN
Type: gaussmf
Params: [0.07078 0]

Selected variable "kp"

Figure 5.3.3 Membership Function Plots for Outputs kp,ki,kd

Fuzzy Rule Base

According to the input and output membership functions, 49 fuzzy rules for every parameter are administered and shown within the tables below.



```
1. If (e is NN) and (ec is NN) then (kp is PP)(ki is NN)(kd is P) (1)
2. If (e is NN) and (ec is NL) then (kp is PP)(ki is NN)(kd is N) (1)
3. If (e is NN) and (ec is N) then (kp is PL)(ki is NL)(kd is NN) (1)
4. If (e is NN) and (ec is ZE) then (kp is PL)(ki is NL)(kd is NN) (1)
5. If (e is NN) and (ec is P) then (kp is P)(ki is N)(kd is NN) (1)
6. If (e is NN) and (ec is PL) then (kp is ZE)(ki is ZE)(kd is NL) (1)
7. If (e is NN) and (ec is PP) then (kp is ZE)(ki is ZE)(kd is P) (1)
8. If (e is NL) and (ec is NN) then (kp is PP)(ki is NN)(kd is P) (1)
9. If (e is NL) and (ec is NL) then (kp is PP)(ki is NN)(kd is N) (1)
10. If (e is NL) and (ec is N) then (kp is PL)(ki is NL)(kd is NN) (1)
11. If (e is NL) and (ec is ZE) then (kp is P)(ki is N)(kd is NN) (1)
12. If (e is NL) and (ec is P) then (kp is P)(ki is N)(kd is NL) (1)
13. If (e is NL) and (ec is PL) then (kp is ZE)(ki is ZE)(kd is N) (1)
14. If (e is NL) and (ec is PP) then (kp is N)(ki is ZE)(kd is ZE) (1)
15. If (e is N) and (ec is NN) then (kp is PL)(ki is NN)(kd is ZE) (1)
16. If (e is N) and (ec is NL) then (kp is PL)(ki is NL)(kd is N) (1)
17. If (e is N) and (ec is N) then (kp is PL)(ki is N)(kd is NL) (1)
```

Figure 5.3.4 Fuzzy Rule Editor for Kp ,Ki and Kd

e	ce						
	NN	NL	N	ZE	P	PL	PP
NN	PP	PP	PL	PL	P	ZE	ZE
NL	PP	PP	PL	P	P	ZE	N
N	PL	PL	PL	P	ZE	N	N
ZE	PL	PL	P	ZE	N	NL	NL
P	P	P	ZE	N	N	NL	NL
PL	P	ZE	N	NL	NL	NL	NN
PP	ZE	ZE	NL	NL	NL	NN	NN

Table 5.3.1 Fuzzy Rules for Kp

e	ce						
	NN	NL	N	ZE	P	PM	PP
NN	P	N	NN	NN	NN	NL	P
NL	P	N	NN	NL	NL	N	ZE
N	ZE	N	NL	N	N	N	ZE
ZE	ZE	NL	NL	N	N	N	ZE
P	ZE	ZE	ZE	ZE	ZE	ZE	ZE
PL	PP	P	N	P	P	P	PP
PP	PP	PL	PL	P	P	P	PP

Table 5.3.3 Fuzzy Rules for Ki

e	ce						
	NN	NL	N	ZO	P	PM	PP
NN	NN	NN	NL	NL	N	ZE	ZE
NL	NN	NN	NL	N	N	ZE	ZE
N	NN	NL	N	N	ZE	P	P
ZE	NL	NL	N	ZE	P	PL	PL
P	NL	N	ZE	P	P	PL	PP
PL	ZE	ZE	P	P	PL	PP	PP
PP	ZE	ZE	P	PL	PL	PP	PP

Table 5.3.3 Fuzzy Rules for Ki

The Linguistic variables are:

NN: Negative Negative (largest negative)

NL: Negative large (larger negative)N: Negative small (large negative) ZE: Zero

P: Positive small (large positive)

PB: Positive big (larger positive)
PP: Positive Positive (largest positive)
The sizes of the fuzzy rules matrix are [7X7]
Input variables of FLC
(a) error (e)
*(b)*change of error (ce)

The objective of the fuzzy controller will depend only on the rule base and this is frequently composed of IF Clause and THEN- clause. Improved response of the pitch system is feasible with an efficient rule base. The accuracy of output depends on the formation of rules. the principles are framed supported the frequent checking of the output response[13].

- **Defuzzification**

The process of conversion of a fuzzy set into a real number is called defuzzification. Several methods are developed to get real values as outputs. For this application, we employed centroid defuzzification [13].

5.2.3 Adaptive Fuzzy PID Controller

To deal with the changes in working conditions and to make certain optimum control performance, adaptive FLC is required [13]. This thesis proposes a figurative logic controller (FLC) for controlling the blade pitch angle of a turbine.

Here the three parameters of PID control Kp, Ki, Kd are modified by the FLC counting on the values of pitch error e and alter in pitch error “e”. The three parameters of the PID controller are to be adjusted current pitch deviation and alter in pitch deviation .

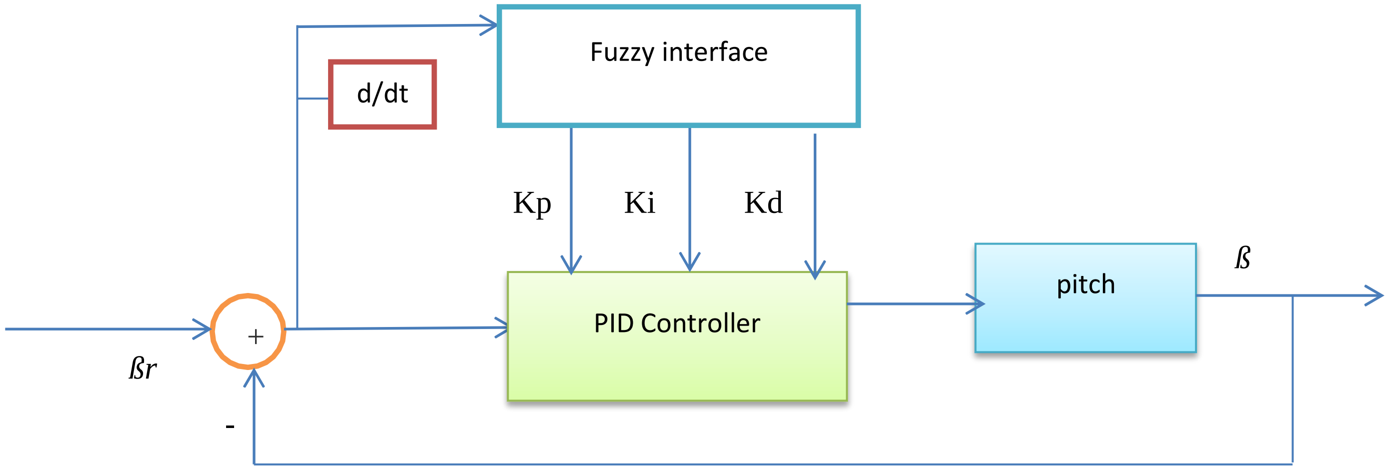


Figure 5.4.1 Fuzzy Adaptive PID Control Block of Pitch System

Kp = Kp (pid) +{ Kpf (fuzzy)* Kp(pid)} (i)

Ki = Ki (pid) + {Kif (fuzzy)*Ki(pid)} (ii)

Kd = Kd (pid) + {Kdf (fuzzy)*Kd(pid)} (iii)

The two inputs of the Adaptive Fuzzy-PID system are the power error (e) and the deviation of power error (ec), shown in Fig.2.2.6. For maintaining the blade pitch angle at optimal value, to protect the WT from any damage at high wind speed, the three parameters Kp, Ki, Kf of the output fuzzy interference are auto-tuning at different wind speeds. The fuzzy rules for each KP, ki, and kd are calculated from Eq. (i), (ii), and (iii)

CHAPTER SIX

6.1 Results and Discussion on Wind Farm Layout Optimization

In this chapter, we describe the wind park layout optimization problem, which may be a crucial problem that must be solved during the planning of a wind park . having the ability to seek out a far better layout results in higher energy production and profit. Results obtained using the Genetic Algorithm are presented and compared to different results obtained by previous works in terms of total power generated within the wind park , optimization function value, and farm efficiency. during this thesis, the AEP of the wind park is calculated but not compared with other works since the result obtained by previous works didn’t include AEP. the amount of the turbine is specified and therefore the optimal configuration for the turbines is obtained by minimizing the target function. The minimum value of the target function is then compared across a variety of the amount of turbines to get the optimal layout of wind turbines to be placed within the wind park . From the SIMULINK result, it are often observed what the optimal placement of wind turbines seems like.

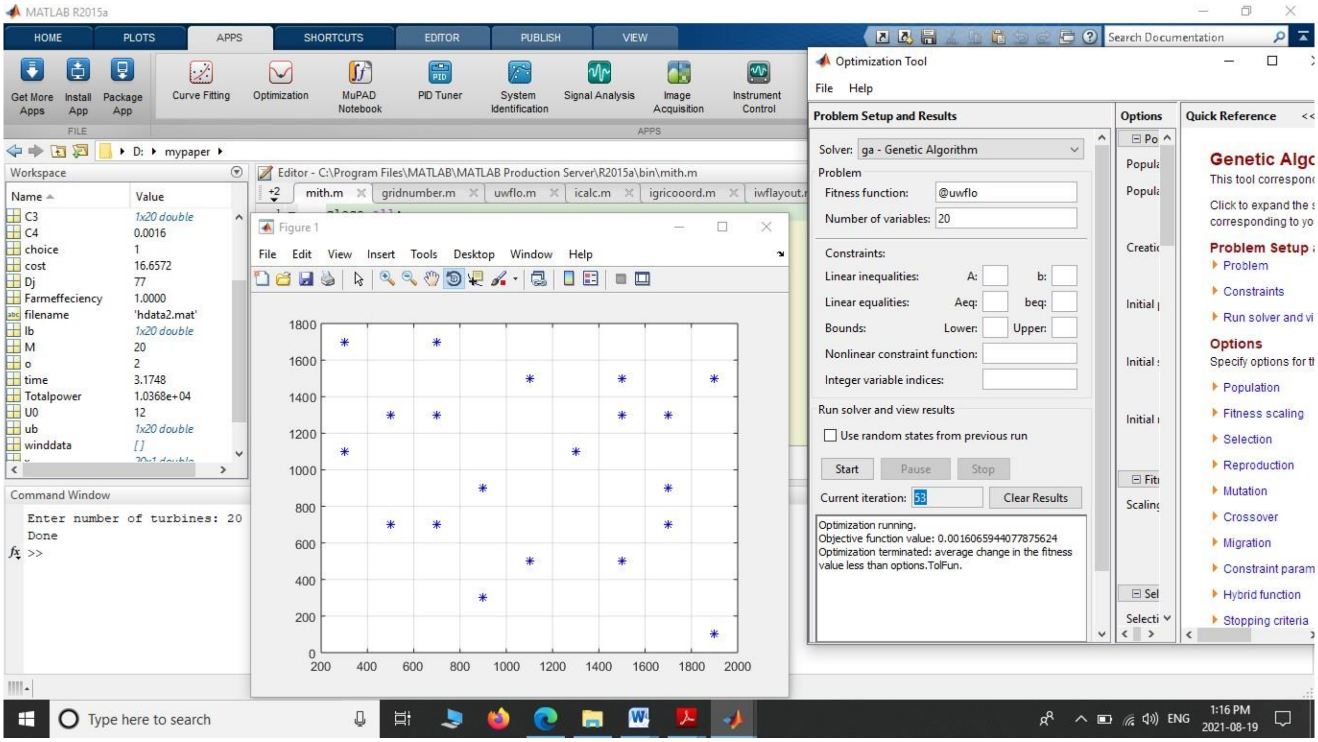
6.1.1 Results of This Study

The parameters of the wind farm layout and the algorithms used in this research are discussed as follows: The site is a square with 2000 by 2000m2 area. The turbine with a rated power of 1500 kW is considered in the layout design.

6.1.1 Observed MATLAB Outputs of this Study.

For illustration, Let us start by optimizing 20 WTs layout for constant wind speed and wind direction.

- Number of Turbines = 20



Workspace

Name	Value
C3	1x20 double
C4	0.0016
choice	1
cost	16.6572
Dj	77
Farmeffeciency	1.0000
filename	'hdata2.mat'
lb	1x20 double
M	20
o	2
time	3.1748
Totalpower	1.0368e+04
U0	12
ub	1x20 double
winddata	[ ]

Command Window

```
Enter number of turbines: 20
Done
>>
```

Optimization Tool

Problem Setup and Results

Solver: ga - Genetic Algorithm

Problem

Fitness function: @uwflo

Number of variables: 20

Constraints:

Linear inequalities: A: b:

Linear equalities: Aeq: beq:

Bounds: Lower: Upper:

Nonlinear constraint function:

Integer variable indices:

Run solver and view results

☐ Use random states from previous run

Start Pause Stop

Current iteration: 53

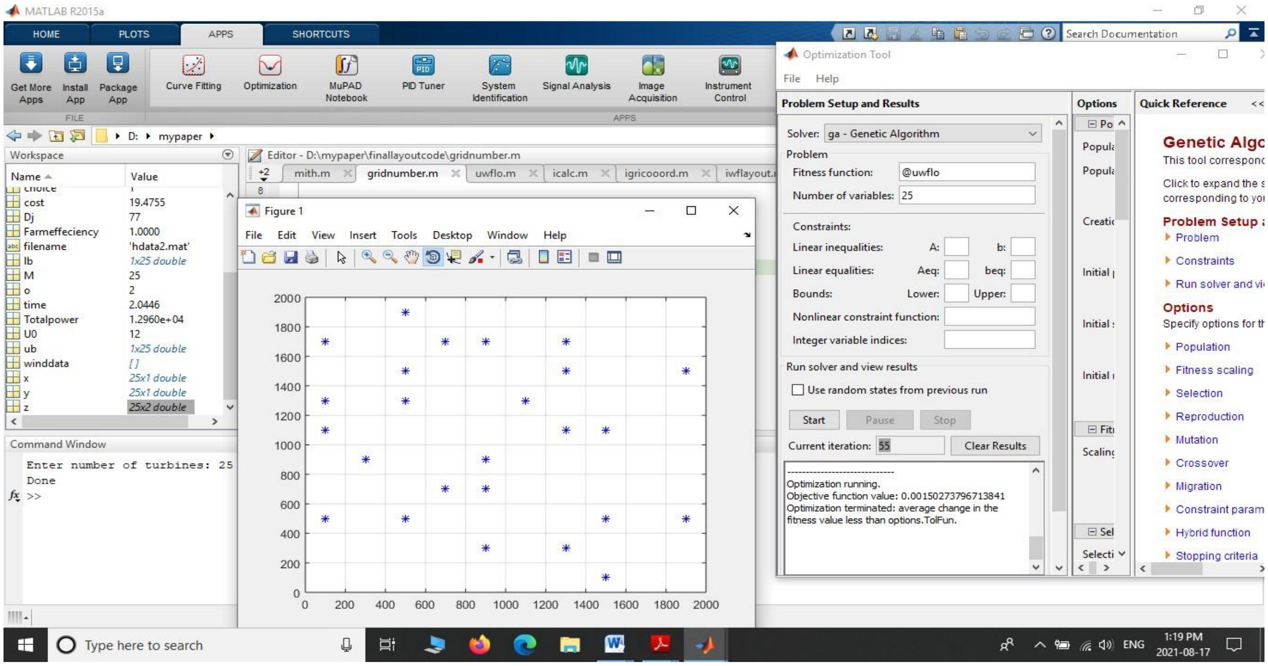
```
Optimization running.
Objective function value: 0.0016065944077875624
Optimization terminated: average change in the fitness
value less than options.TolFun.
```

Figure 6.1.2 Layout Optimization of 20 Wind Turbines of current study

List of WTs	***X coordinate***	***Y coordinate***
1	1900	100
2	900	300
3	1100	500
4	1500	500
5	500	700
6	700	700
7	1700	700
8	900	900
9	1700	900
10	300	1100
11	1300	1100
12	500	1300
13	700	1300
14	1500	1300
15	1700	1300
16	1100	1500
17	1500	1500
18	1900	1500
19	300	1700
20	700	1700

Table 6.1.3 x-y coordinates of 20 Wind Turbines of current study

□ .Number of Turbines = 25



Workspace

Name	Value
choice	1
cost	19.4755
Dj	77
Farmeffeciency	1.0000
filename	'hdata2.mat'
lb	1x25 double
M	25
o	2
time	2.0446
Totalpower	1.2960e+04
U0	12
ub	1x25 double
winddata	[]
x	25x1 double
y	25x1 double
z	25x2 double

Command Window

```
Enter number of turbines: 25
Done
>>
```

Problem Setup and Results

Solver: ga - Genetic Algorithm

Problem

Fitness function: @uwflo

Number of variables: 25

Constraints:

Linear inequalities: A: b:

Linear equalities: Aeq: beq:

Bounds: Lower: Upper:

Nonlinear constraint function:

Integer variable indices:

Run solver and view results

☐ Use random states from previous run

Current iteration: 55

```
------------------------------
Optimization running.
Objective function value: 0.00150273796713841
Optimization terminated: average change in the
fitness value less than options.TolFun.
```

Figure 6.1.3 Optimized Layout for 25 Wind Turbines of current study

List of WTs	***X coordinate***	***Y coordinate***
1	1500	100
2	900	300
3	1300	300
4	100	500
5	500	500
6	1500	500
7	1900	500
8	700	700
9	900	700
10	300	900
11	900	900
12	100	1100
13	1300	1100
14	1500	1100
15	100	1300
16	500	1300
17	1100	1300
18	500	1500
19	1300	1500
20	1900	1500
21	100	1700
22	700	1700
23	900	1700
24	1300	1700
25	500	1900

Table 6.1.4 x-y coordinates of 25 Wind Turbine of current study

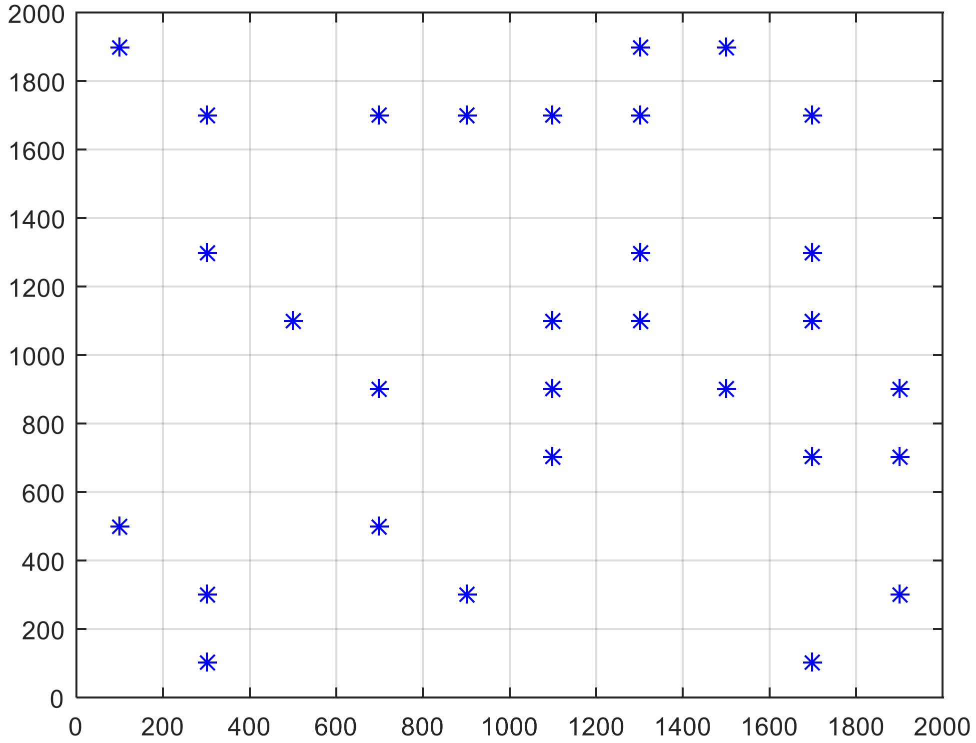


Figure 6.1.4 Optimized Layout 30 Wind Turbines of current study

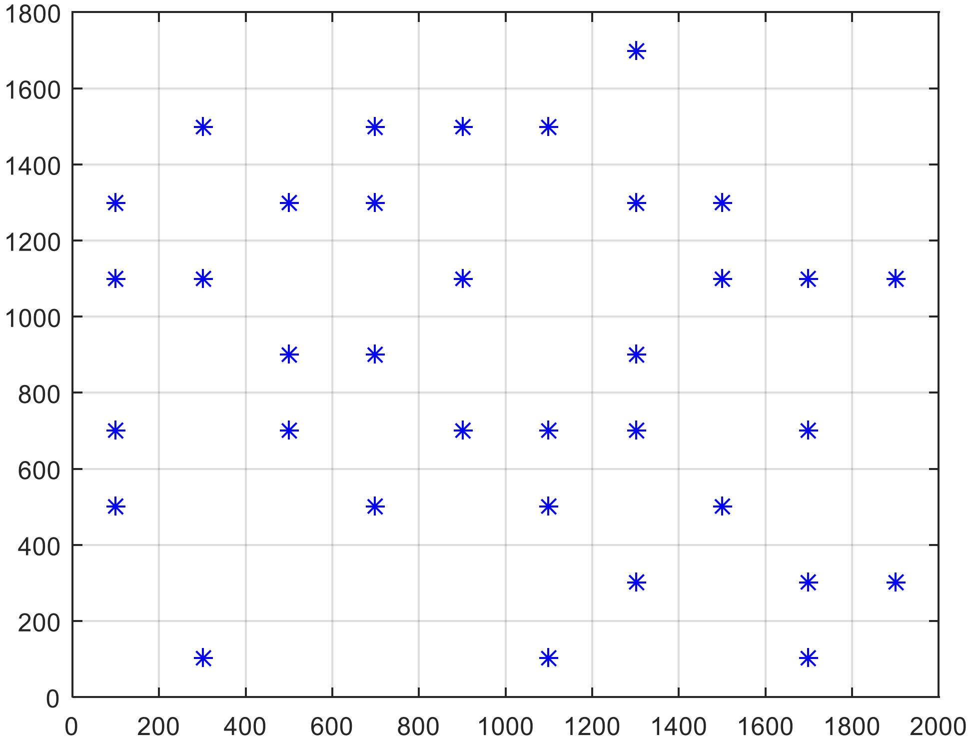


Figure 6.1.5 Optimized Layout 35 Wind Turbines of current study

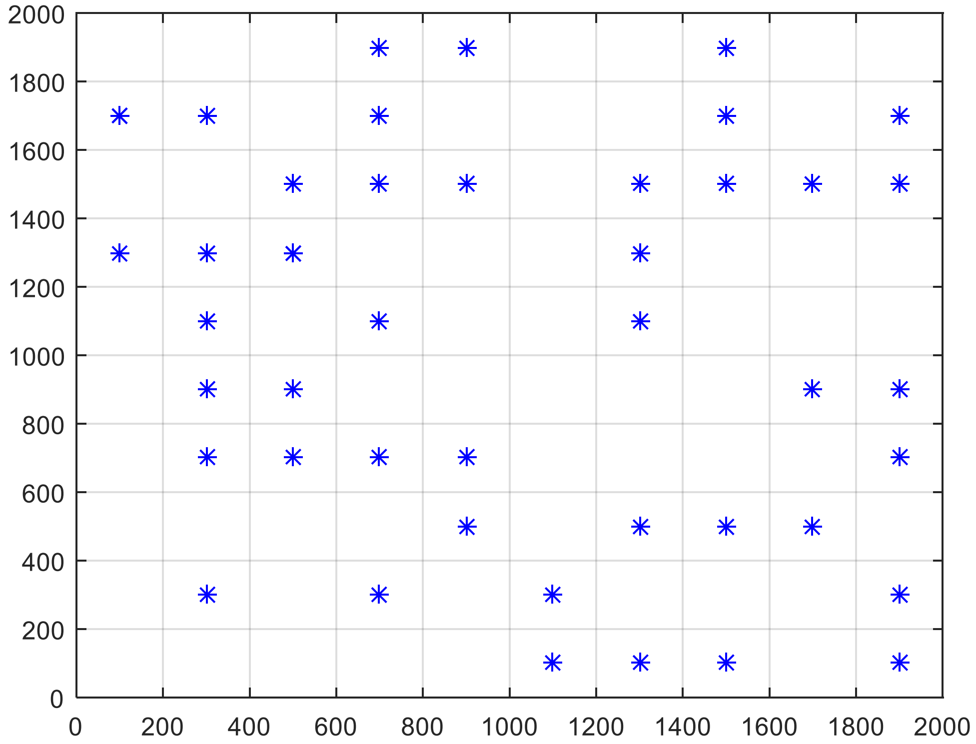


Figure 6.1.6 Optimized Layout 55 Wind Turbines

Number of WTs(N)	Cost	Gross power(kw)	Total power(Kw)	AEP(MWh)	Objective Function value	Farm Efficiency	Wake loss(%)
20	16.6572	10365	10368	90,823.7	$1.61x10^{-3}$	1	0
25	19.4755	12960	12960	113,529.6	$1.28x10^{-3}$	1	0
30	22.0888	15552	15552	136,235.5	$1.07x10^{-3}$	1	0
35	24.7177	18144	18120	158,731.2	$1.3623 x10^{-3}$	0.9983	0.13
40	27.4905	20736	20547	179,991.7	$1.3254x10^{-3}$	0.9909	0.9
55	36.7616	28512	26772	234,552.7	$1.291 x10^{-3}$	0.9347	2.1

Table 6.1.5 Summary of optimization results of current study

As it are often observed from summary table 6.1.2, we will conclude that the wake loss is minimized by proper layouts of N=20, N=25, N=30 because the entire power generated, is adequate to the expected net power. And also the target function value is decreasing. And Genetic algorithm has selected a correct arrangement of WTs which reduces wake loss.

A few bit variations are seen N=35 and N=40 when the amount of turbines increases within the given wind park area, the share wake loss is additionally increasing

For N=55 an outsized wake loss is observed due to the layout and therefore the wind park area 2000mx2000m can hold only 40 WTs with very less wake.

The test runs show that the proposed algorithm works needless to say and is in a position to optimize a given wind park layout problem.

6.2 Results of this study as compared to previous studies

This case was attempted by Mosetti et al.[24] , Grady et al [24], and Marmidis et al.[24] employing a grid with five turbine rotor diameters (200 m) because the distance between adjacent grid points. A turbine are often placed at a grid point which suggests the minimum distance between any two turbines are often 200 m. The optimal layouts and results from these studies are presented in Figures 6.2.1 – 6.2.3 and Table 6.2.1. The optimal configurations from previous studies were compared with these studies and results are presented alongside the reported leads to Table 6.2.1. Note that the efficiency presented within the results is that the efficiency of the wind park and will not be confused with the efficiency of the turbine . It represents the particular power produced from the wind park compared to the facility produced from an equivalent number of turbines experiencing the free-stream wind speed (i.e., no-wake losses within the wind farm).

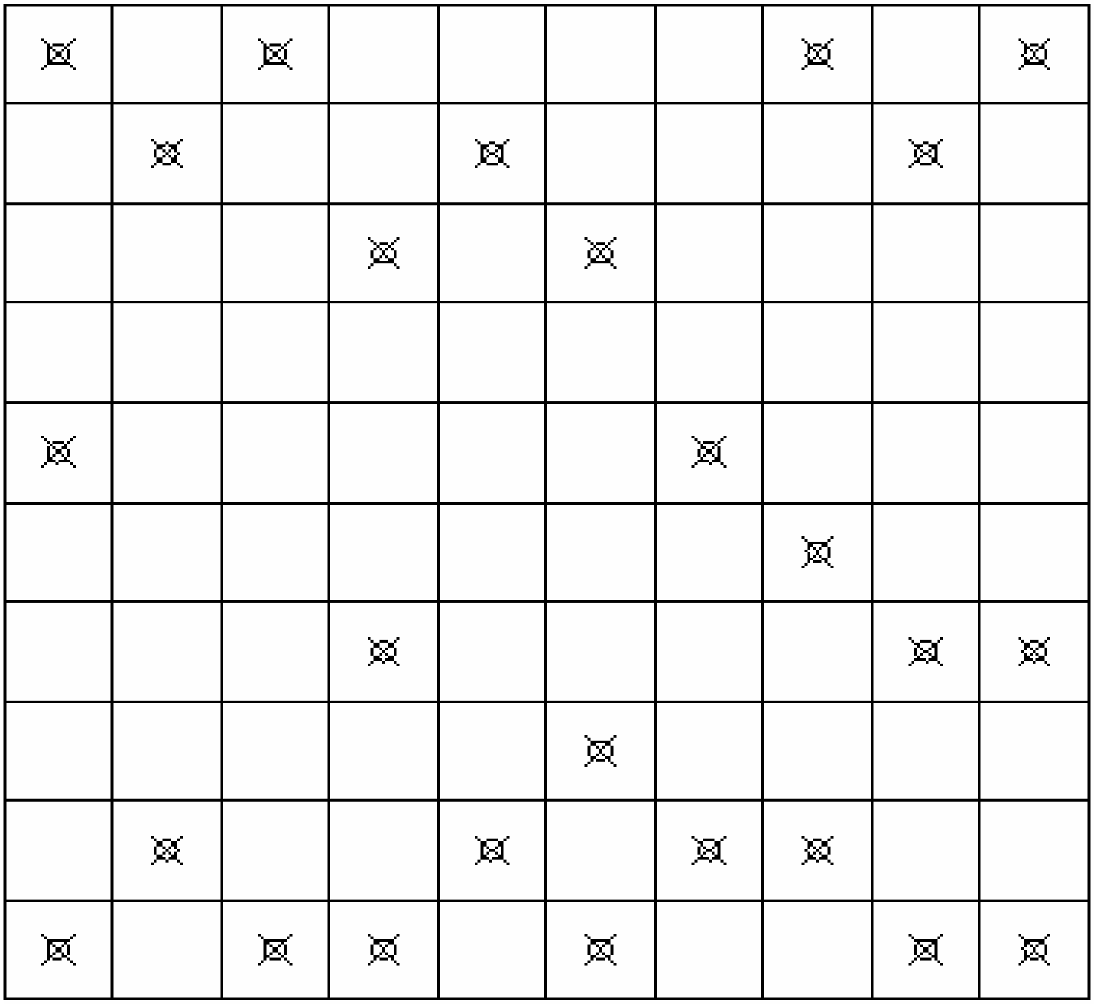


Figure 6.2.1 Mosetti et al.'s optimal layout for 26 WT

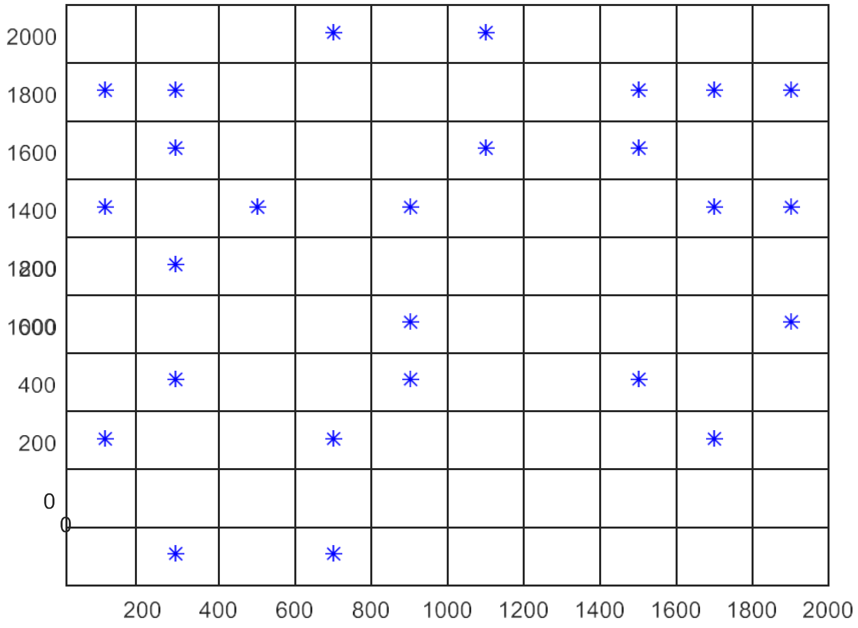


Figure 6.2.2 optimal layout for 26 WTs current study[24

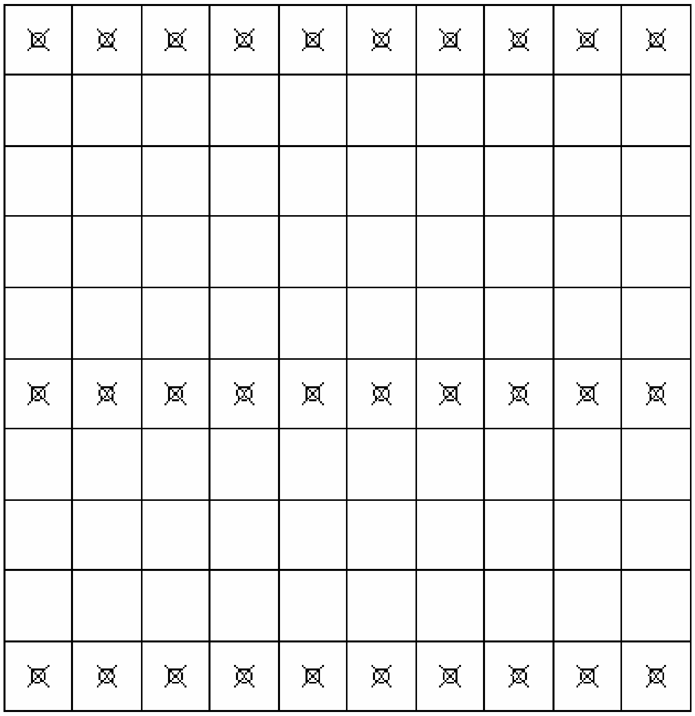


Figure 6.2.3 Grady et al.'s optimal layout for 30 WTs

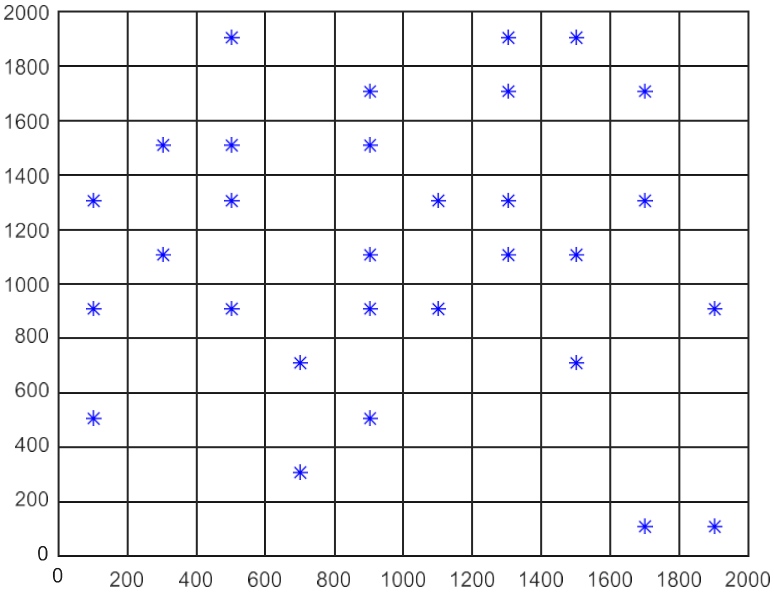


Figure 6.2.4 optimal layout for 30 WTs current study

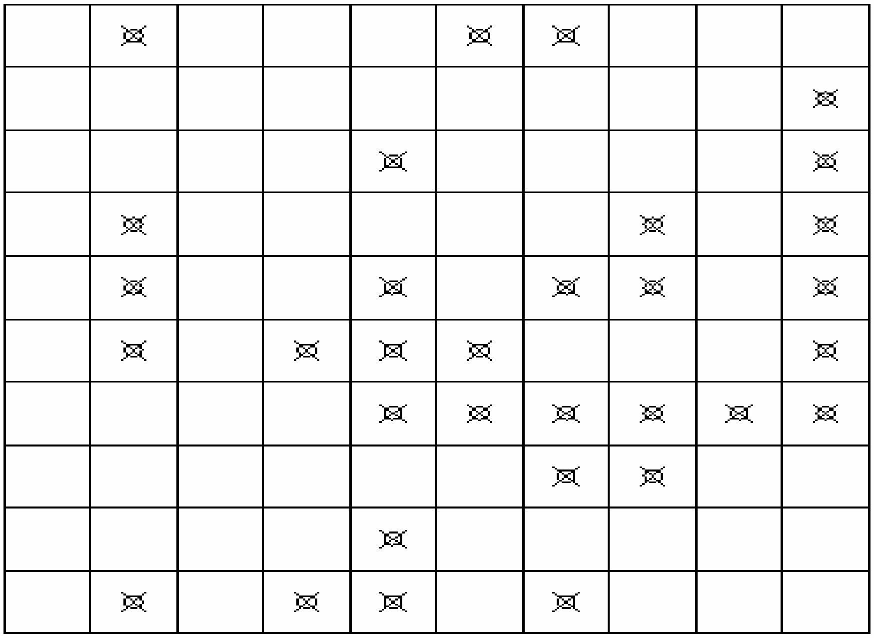


Figure 6.2.5 Marmidis et al.'s optimal layout for 32 WTs [24]

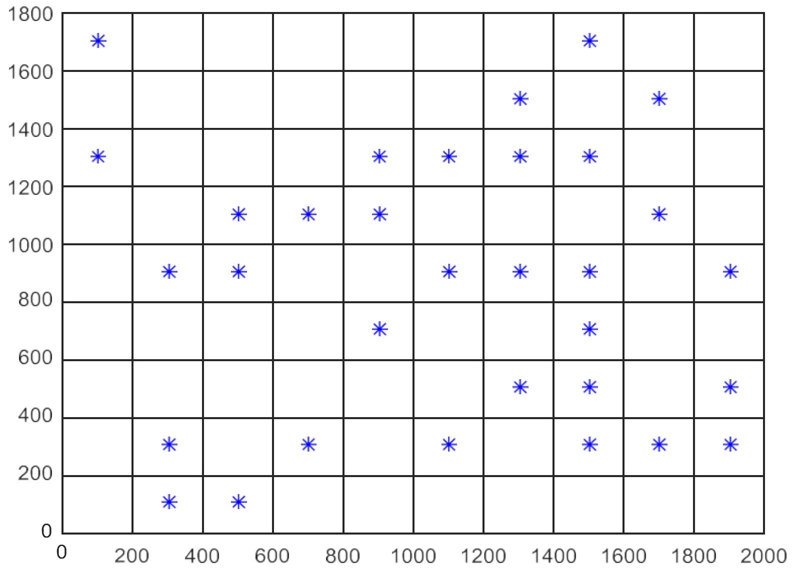


Figure 6.2.6 Optimal layout for 32 WTs current study

	Mosetti et al	This Study	Grady etal	This study	Marmidis et al	ANSHUL MITTAL	This Study
Number of Turbines	26	26	30	30	32	32	32
Total power(kw)	12352	13478	14336	15463	16395	11432	16565
Obj.Functin value	$1.6197x10^{-3}$	$1.484x10^{-3}$	$1.5436x10^{-3}$	$1.42x10^{-3}$	$1.41x10^{-3}$	$2.227x10^{-3}$	$1.39\ x10^{-3}$
Efficiency	91.769	99	92.015	99	92.181	68	97.9

Table 6.2.1 Results of Previous studies as compared to this study

The layout reported by Mosetti et al.[24]

The first turbine in any column is placed within the first three rows apart from column seven is where the primary turbine appears in row five. Similarly, the last turbine altogether the columns is placed within the last two rows.

Grady et al.[24]

The results reported by Grady et al. are symmetrical because he optimized just one column and translated the results to all or any the columns. The symmetrical configuration has an objective function value less than that of Mosetti et al. Thus, it are often said that Mosetti et al. weren't ready to reach the optimal solution but were close because the pattern in layout reported by Grady et al. are often seen in Mosetti et al.‟s layout.

Marmidis et al [24]

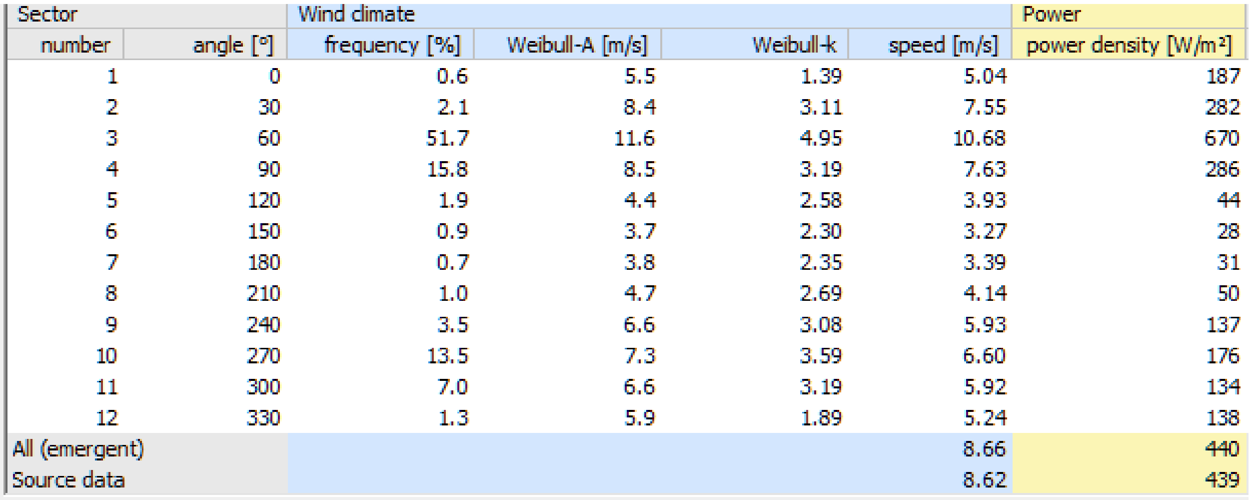
The figure shows the layout presented by Marmidis et al. and it's questionable because there are not any wind turbines in columns one and three. this suggests these two columns aren't utilized because the wind direction is along the column. Moreover, in column ten, six wind turbines are placed back to back which can severely affect the efficiency and power production from these wind turbines.

Discussion on results of this study as compared to the above three studies.

Wind farm layout optimization using Genetic Algorithm(this study) calculations are in agreement with those reported by Marmidis et al. Even if there is a small difference in the power output and objective function value this inconsistency can be modified by improving the layout of the two turbines in column 3 and 10. But the result was reported by Mosetti et al and Grady. et.al was very far from this study. The estimated power output from Mosetti et wind farm for 26 turbines was a 12352KW objective function value of 1.6197×10-3, and the result obtained by this study is power 13478KW and 1.4×10-3. Grady et al also reported 14310KW and1.5436×10-3 total power and objective function value respectively. For 30 turbines the result of this study for 30 turbines is 15463KW total power and 1.42×10-3 function value. This shows that the layout reported by Mosetti et al. and Grady et al. cannot be best since the current study reported layout produces more power with the same number of wind turbines. Therefore it is clear that the results obtained in this research are better than results from three of the studies referred to earlier. Hence maximizing the total power of the wind farm by minimizing the wake loss using optimal layout is succeeded.

Wind Turbines layout optimization under variant wind speed and direction.

The variations of the annual distribution of wind speed and directions are modeled using a 2-parameter Weibull distribution (table 1)[1]. The wind turbines in the wind farm are arranged in a grid form with inter distance of 5 times the diameter of the Turbine’s rotor blade. To avoid mutual interference and harvest the maximum energy, the wind turbines are placed in the prevailing wind direction. All design layouts are optimized under the mean wind speed of 12m/s and the dominant wind direction of(45deg to 90 deg) East North East (ENE) sector 3 of the wind rose (fig)[1]. The Annual yield of Energy Production (AEP) is calculated according to the annual wind distribution of the site.



Sector		Wind climate				Power
number	angle [°]	frequency [%]	Weibull-A [m/s]	Weibull-k	speed [m/s]	power density [W/m²]
1	0	0.6	5.5	1.39	5.04	187
2	30	2.1	8.4	3.11	7.55	282
3	60	51.7	11.6	4.95	10.68	670
4	90	15.8	8.5	3.19	7.63	286
5	120	1.9	4.4	2.58	3.93	44
6	150	0.9	3.7	2.30	3.27	28
7	180	0.7	3.8	2.35	3.39	31
8	210	1.0	4.7	2.69	4.14	50
9	240	3.5	6.6	3.08	5.93	137
10	270	13.5	7.3	3.59	6.60	176
11	300	7.0	6.6	3.19	5.92	134
12	330	1.3	5.9	1.89	5.24	138
All (emergent)					8.66	440
Source data					8.62	439

Figure 6.2.7 Weibull Distribution of wind climate [1]

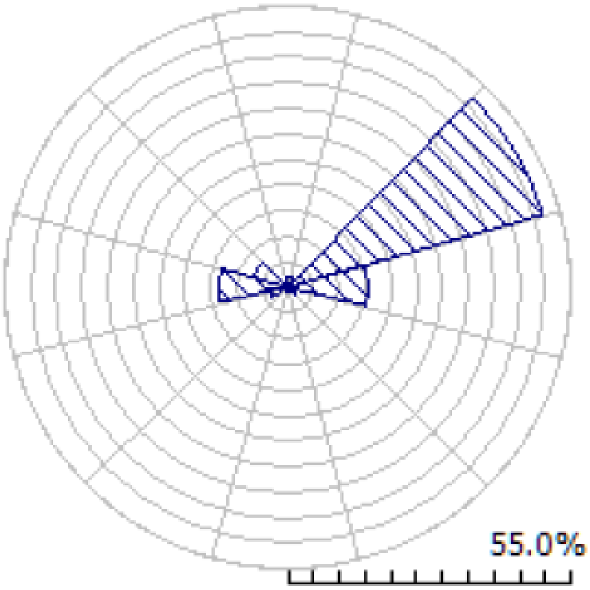


Figure 6.2.8 wind rose, showing the relative frequencies of wind direction for each sector [1]

There are 12 sectors in the wind rose each sector comprises 30 degrees, sector 1 starts from 345 degrees to 15 degrees. In this sector, the midpoint of the degree range is 0 degrees. Then the second sector starts from 15 degrees to 45 degrees again the midpoint is 30 degrees, that is the arrangement as it can be seen in the wind rose figure.[1]

The optimal layout of wind turbines according to the wind direction is given below.

1. The layouts of 30 turbines to dominant wind direction(60 deg) and wind speed =12 m/s

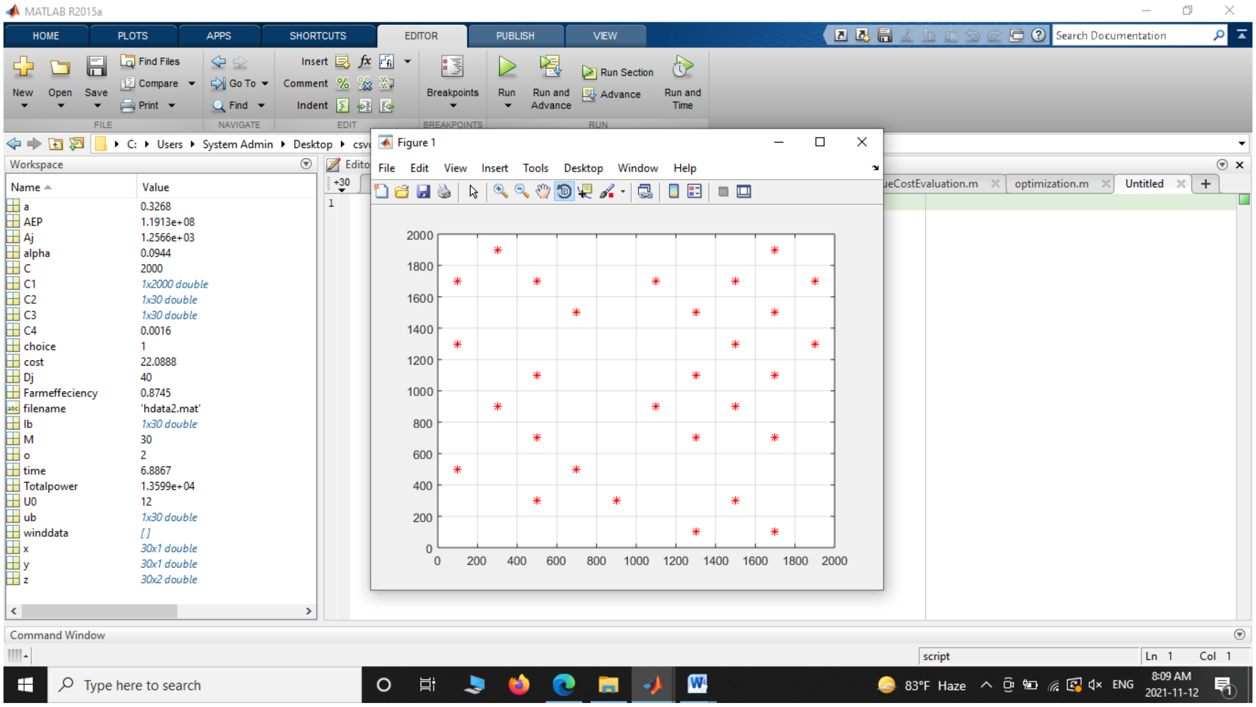
according to the genetic algorithm optimization method developed in this study, most turbines are arranged in the dominant wind direction as observed in the outputs below.

AEP = 119.13Gwhr

Total power of the wind Farm = 13,599kw

Farm efficiency = 87.47 %

Objective function value = 1.43x10^{-3}



Workspace

Name	Value
a	0.3268
AEP	1.1913e+08
Aj	1.2566e+03
alpha	0.0944
C	2000
C1	1x2000 double
C2	1x30 double
C3	1x30 double
C4	0.0016
choice	1
cost	22.0888
Dj	40
Farmeffeciency	0.8745
filename	'hdata2.mat'
lb	1x30 double
M	30
o	2
time	6.8867
Totalpower	1.3599e+04
U0	12
ub	1x30 double
winddata	[ ]
x	30x1 double
y	30x1 double
z	30x2 double

Figure 6.2.9 optimal layout for 30 WTs current study

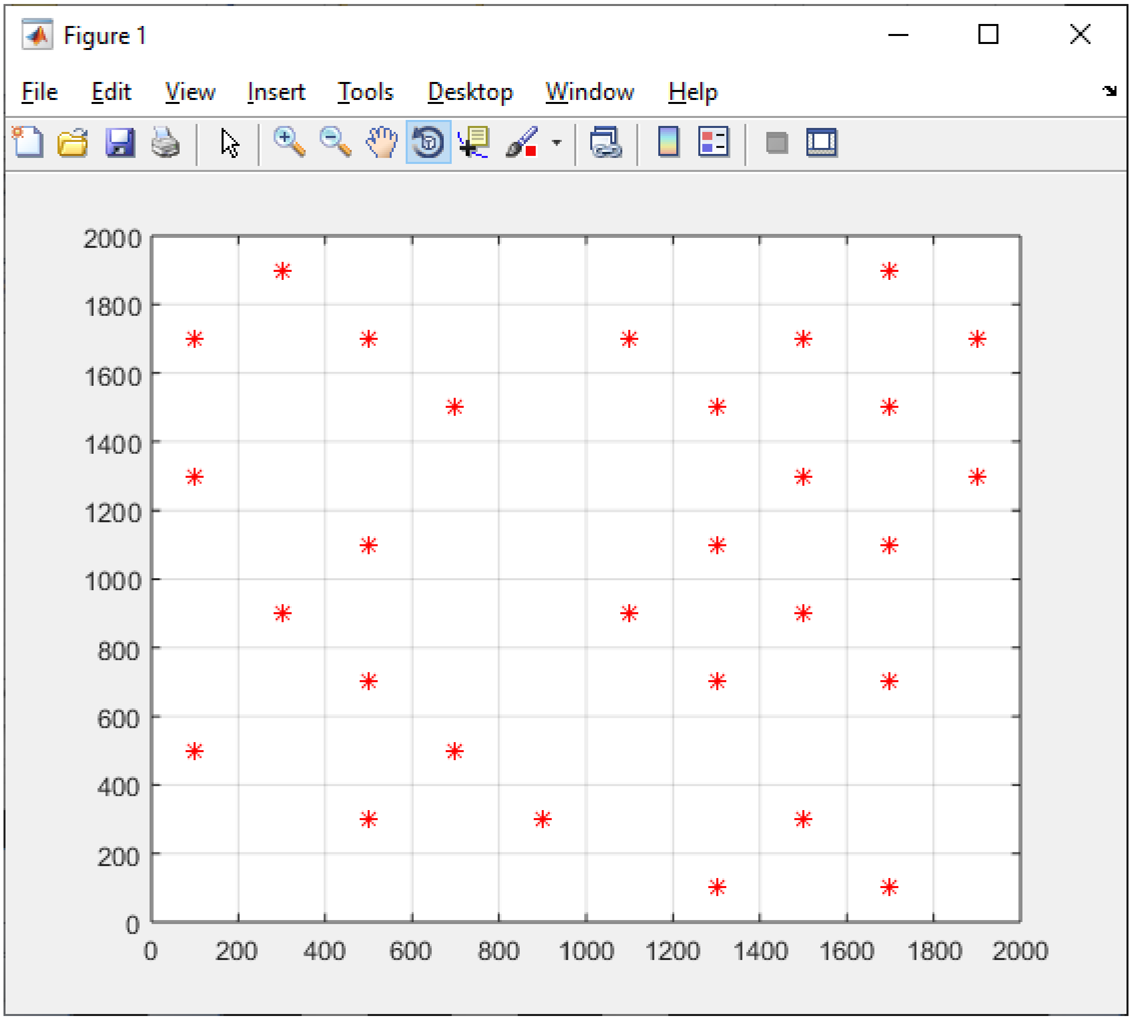


Figure 6.2.10 optimal layout for 30 WTs current study to the dominant wind direction

Seq.No Of WTs	X-coord.	Y-Coord.
1	1300	100
2	1700	100
3	500	300
4	900	300
5	1500	300
6	100	500
7	700	500
8	500	700
9	1300	700
10	1700	700
11	300	900

12	1100	900
13	1500	900
14	500	1100
15	1300	1100
16	1700	1100
17	100	1300
18	1500	1300
19	1900	1300
20	700	1500
21	1300	1500
22	1700	1500
23	100	1700
24	100	1700
25	500	1700
26	1100	1700
27	1500	1700
28	1900	1700
29	300	1900
30	1700	1900

Table 6.2.2 x-y coordinates of 30 Wind Turbines of this study

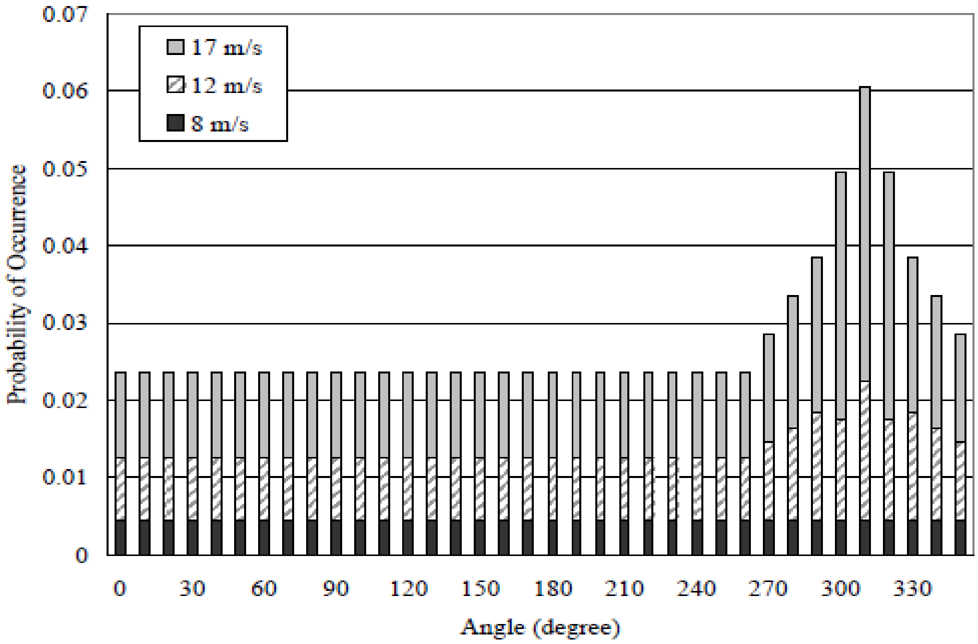


Fig 6.2.11 Wind distribution for variable wind speed and direction [24]

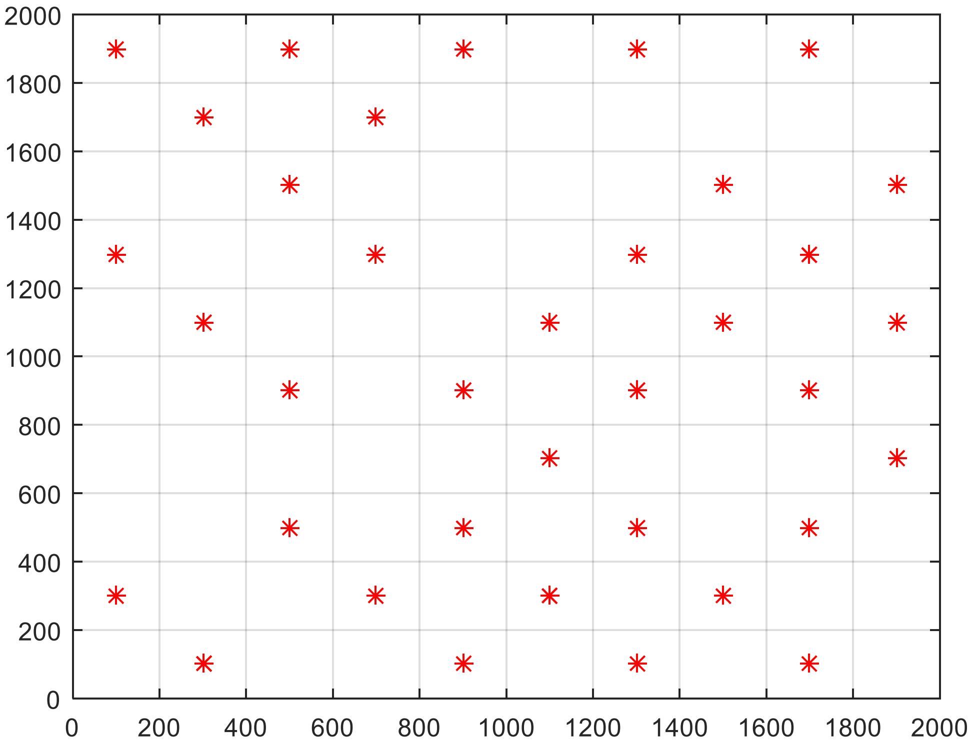
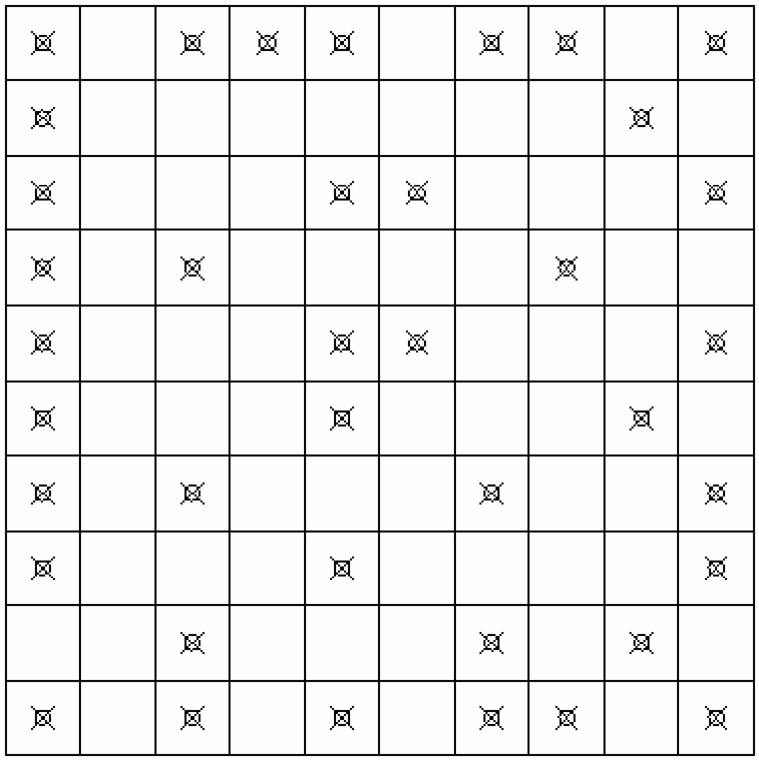


Fig 6.2.12 This study optimal layout for variable speed and wind direction for 39 wind turbines



☒		☒	☒	☒		☒	☒		☒
☒								☒	
☒				☒	☒				☒
☒		☒					☒		
☒				☒	☒				☒
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☒				☒					☒
		☒				☒		☒	
☒		☒		☒		☒	☒		☒

Fig 6.2.13 Grady et al.’s optimal layout for variable speed and wind direction

The wind farm runs at a 54 percent efficiency, according to the arrangement stated by Grady et al. for 39 wind turbines (fig.6.2.13).Wake losses deplete the energy that could be transformed to useful power. Furthermore, the cost per unit of power is 1.366010-3, which is prohibitively expensive.

[24].When compared to the power of Grady et al investigation, .'s this study reported a better layout optimization. According to GA solutions, the wind turbines are spread around the wind farm as seen in figure.The farm efficiency is 83 percent, with a 12.5% loss in overall electricity.

Furthermore, the objective function value is 1.341x10-3, which is higher than in the prior study.

6.2 The Controllers' Simulation Results

In this chapter, we'll develop two controllers to control the turbine's pitch angle, as well as implement the controllers in Simulink to see how they work and what the outcomes are.

6.3.1 Plant Simulation Without Controllers

To check the output, we first replicate the turbine system without any controllers.
The Simulink model of a turbine with no controllers is shown below.

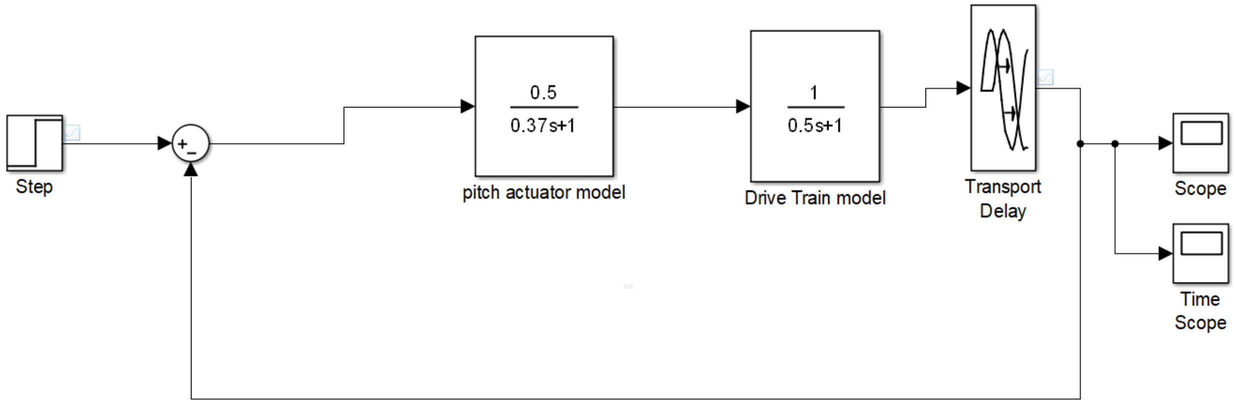
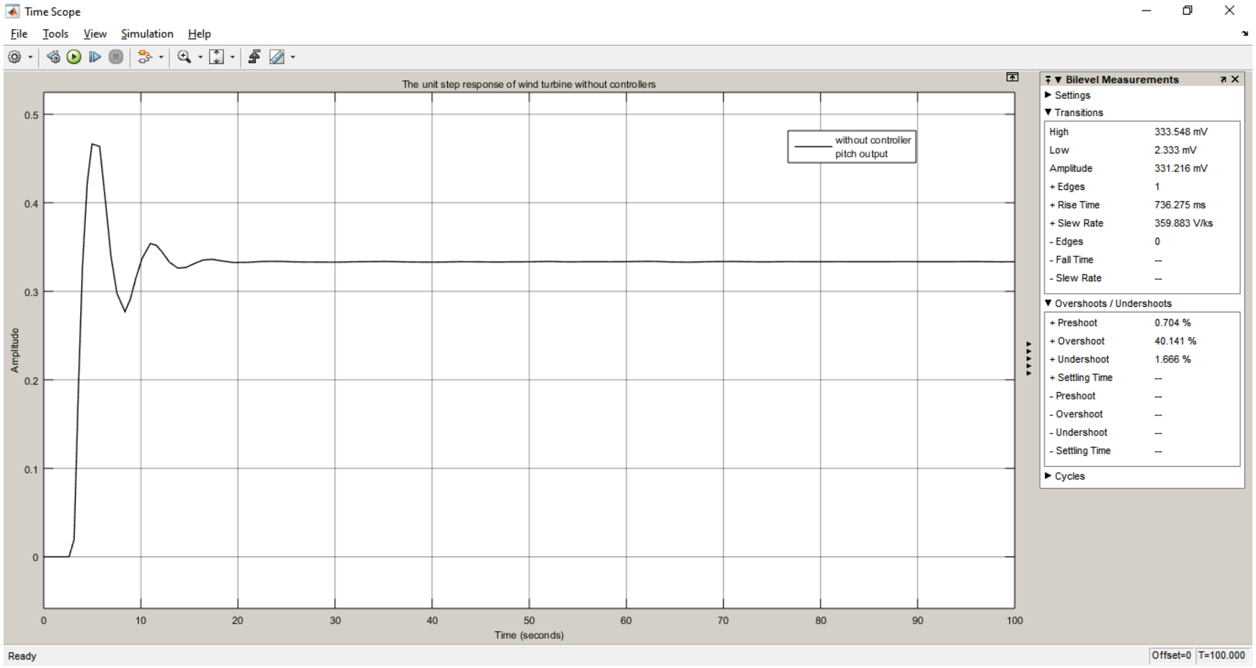


Figure 6.3.1 Simulink Wind Turbine Model without Controllers[5]

- The pitch actuator is used to turn blades along their longitudinal axis.[33]
- The Drive train is composed of the gearbox and the generator,the necessary components that turbines need to produce electricity [33]



```
Bilevel Measurements
▶ Settings
▼ Transitions
High              333.548 mV
Low               2.333 mV
Amplitude         331.216 mV
+ Edges           1
+ Rise Time       736.275 ms
+ Slew Rate       359.883 V/ks
- Edges           0
- Fall Time       --
- Slew Rate       --
▼ Overshoots / Undershoots
+ Preshoot        0.704 %
+ Overshoot       40.141 %
+ Undershoot      1.666 %
+ Settling Time   --
- Preshoot        --
- Overshoot       --
- Undershoot      --
- Settling Time   --
▶ Cycles
```

Figure 6.3.2 The unit step response of wind turbine without controllers

Time Domain	**Without Controller**
Delay Time(s)	**2**
Rise Time(s)	**859.760**
Settling Time(s)	**21**
Peak Overshoot	**40.921%**

Table 6.3.1 Time Domain Specification for Unit step Input without Controller

Figure 6.3.2 depicts the unit step response of a wind turbine pitch control system without a controller.

Because the input is a unit step with a steady state value that is not 1, we do not get the intended output.

In addition, the overshoot is 40.921 percent, and the undershoot is extremely high, resulting in system instability.Table 6.3.1 lists the time domain requirements obtained from the response graph.

6.3.2 Conventional PID Controller Implementation

Fg.6.3.3 shows the Simulink model of a wind turbine pitch control system with a traditional PID controller and the PID controller's control settings.The model is simulated, and the results are shown in the following section.

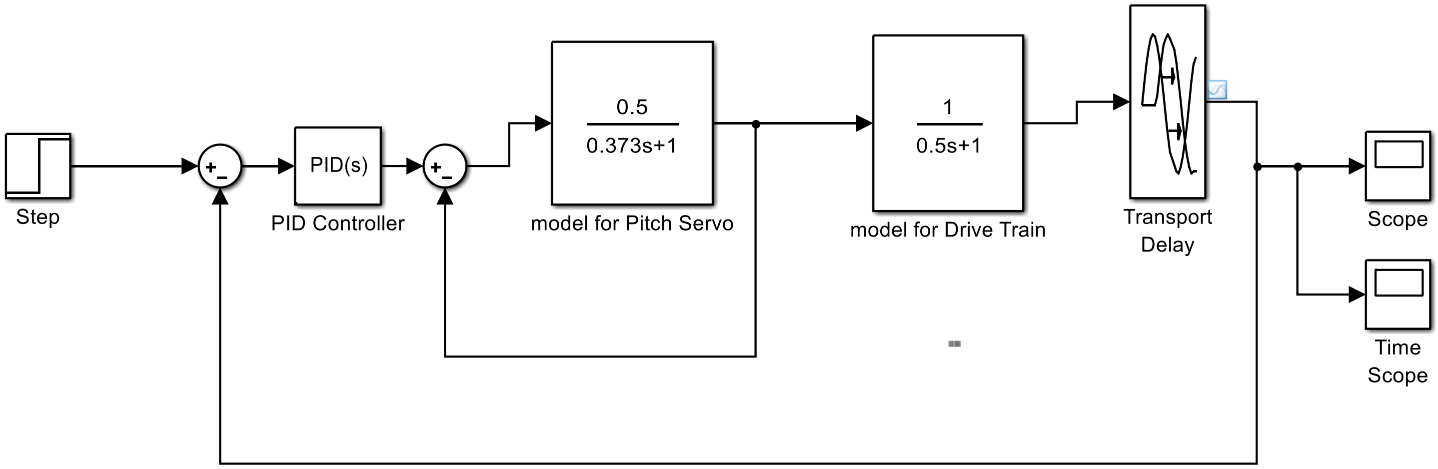
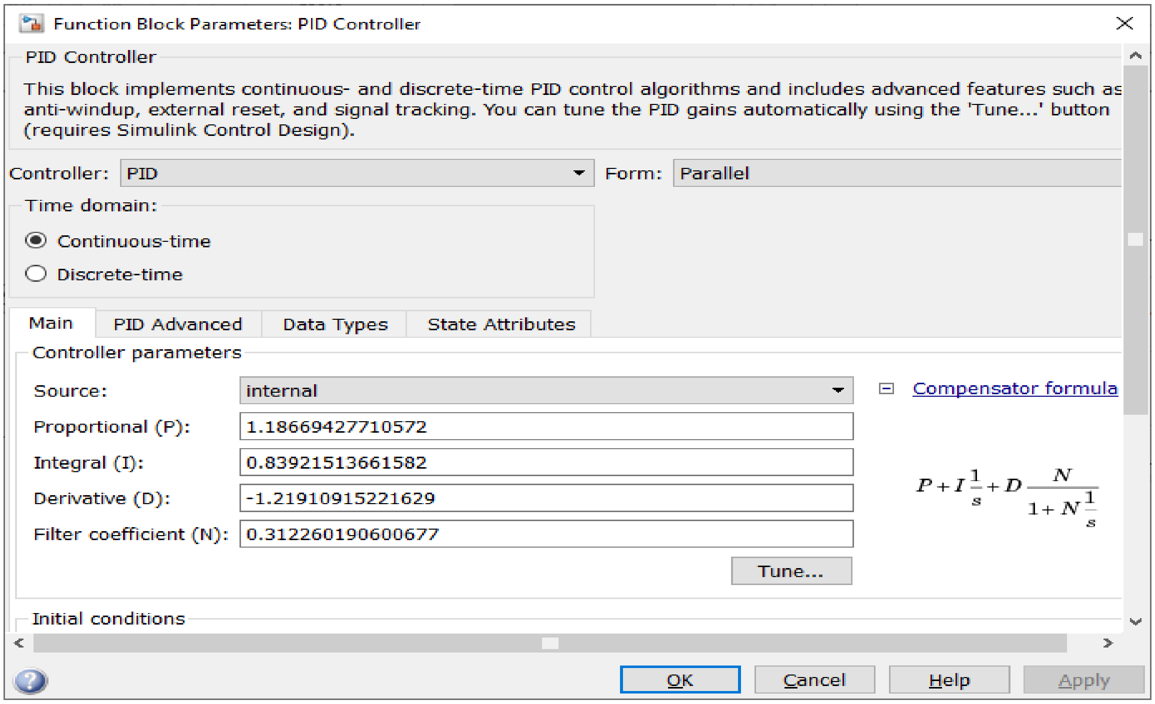


Figure 6.3.3 Simulation diagram of conventional PID controller for pitch control [5]



PID Controller

This block implements continuous- and discrete-time PID control algorithms and includes advanced features such as anti-windup, external reset, and signal tracking. You can tune the PID gains automatically using the 'Tune...' button (requires Simulink Control Design).

Controller: PID

Form: Parallel

Time domain:

● Continuous-time

○ Discrete-time

Controller parameters

Source: internal

Proportional (P): 1.18669427710572

Integral (I): 0.83921513661582

Derivative (D): -1.21910915221629

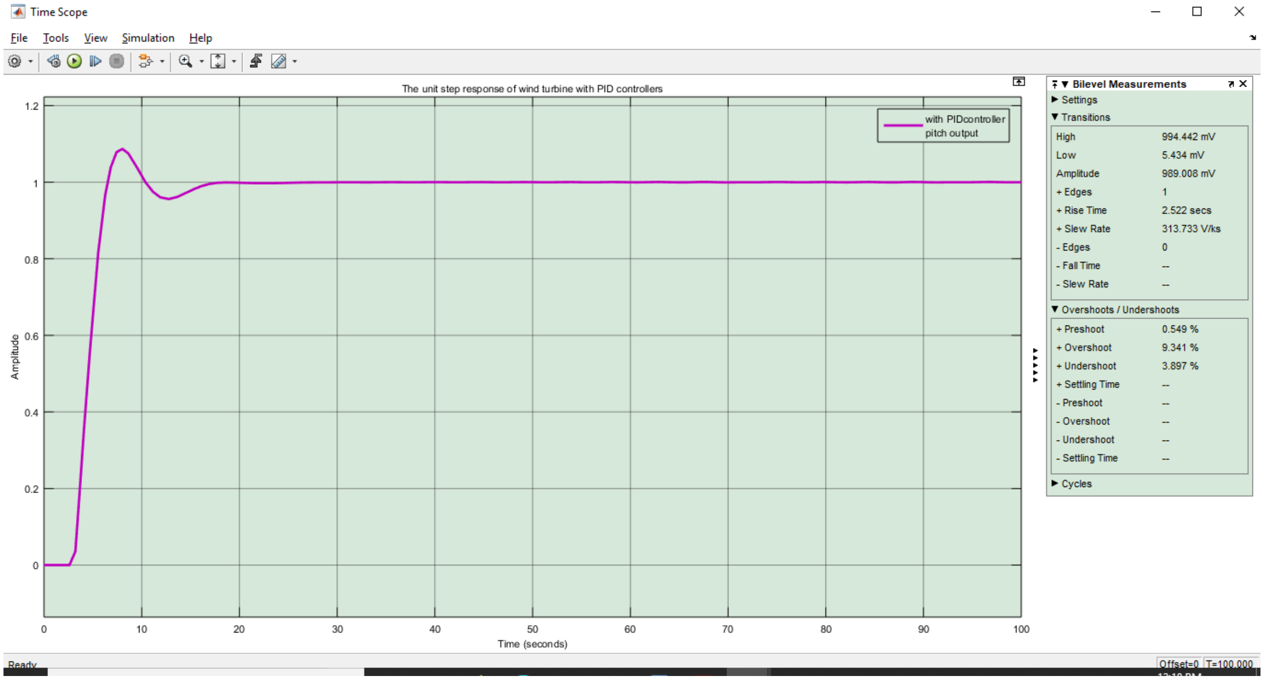
Filter coefficient (N): 0.312260190600677

⊟ Compensator formula

$$P+I\frac{1}{s}+D\frac{N}{1+N\frac{1}{s}}$$

Figure 6.3.4 PID Controller Parameters

6.3.2 Simulation of the Plant with PID Controller



```
Bilevel Measurements
▶ Settings
▼ Transitions
High                994.442 mV
Low                 5.434 mV
Amplitude           989.008 mV
+ Edges             1
+ Rise Time         2.522 secs
+ Slew Rate         313.733 V/ks
- Edges             0
- Fall Time         --
- Slew Rate         --
▼ Overshoots / Undershoots
+ Preshoot          0.549 %
+ Overshoot         9.341 %
+ Undershoot        3.897 %
+ Settling Time     --
- Preshoot          --
- Overshoot         --
- Undershoot        --
- Settling Time     --
▶ Cycles
```

Figure 6.3.5 The unit step response of wind turbine with PID controller

Time Domain	**With PID Controller**
Delay Time(s)	**2**
Rise Time(s)	**2.522**
Settling Time(s)	**21**
Peak Overshoot	**9.341%**

Table 6.3.2 Time Domain parameters for Unit step Input with PID Controller

Figure 6.3.5 depicts the turbine pitch system's unit step reaction.

The response graphs reveal time-domain requirements, which are summarized in Table 6.3.2.

In comparison to the turbine model with no controllers, we found less rise time (4.522sec), settling time (21%), and peak overshoot of 9.341 percent with the PID controller.

6.1 Fuzzy Adaptive PID Controller Implementation

Fig.6.3.6 shows a Simulink model of a wind turbine pitch control system with a fuzzy adaptive PID controller.

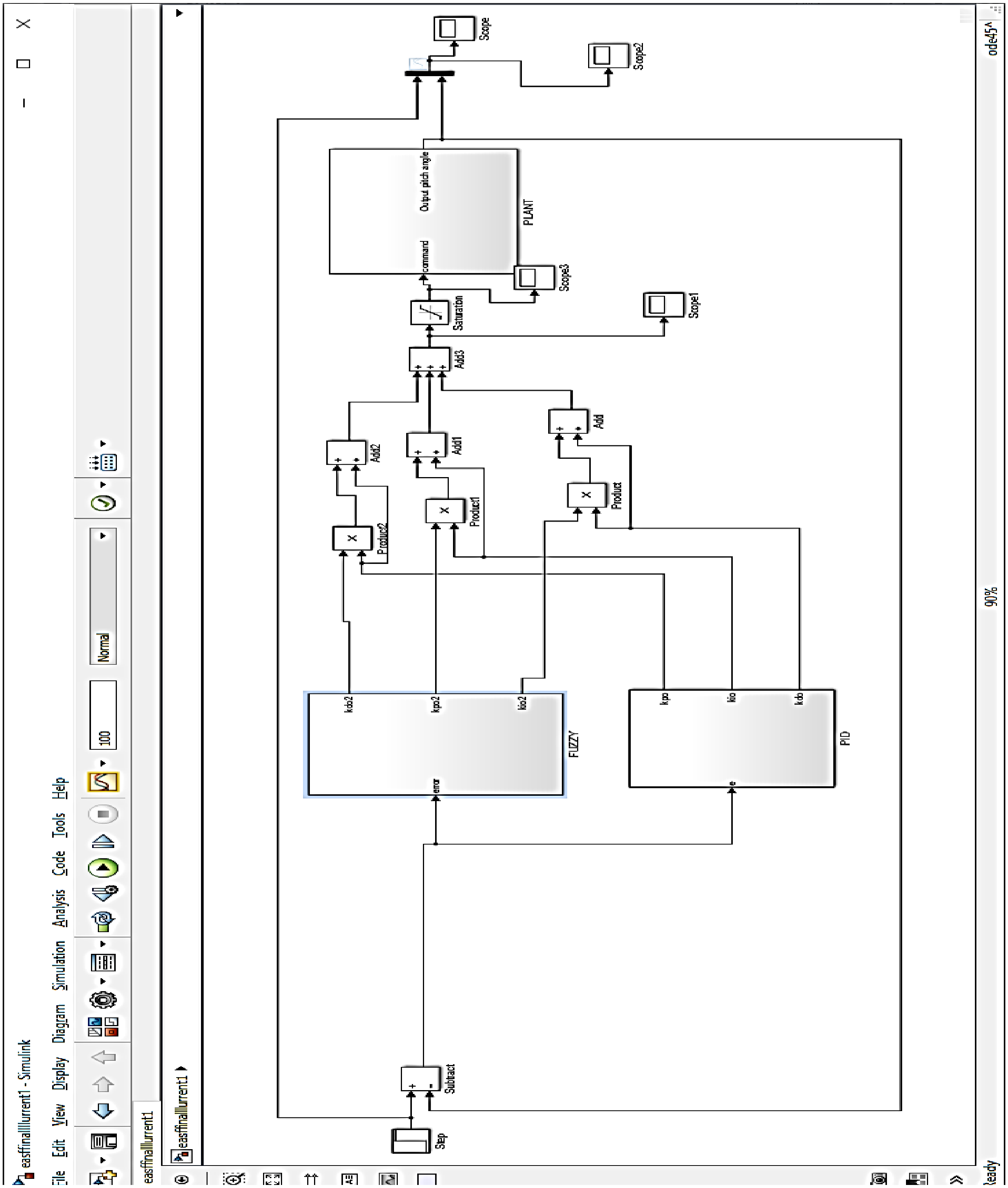


Figure 6.3.6 Simulation diagram of Adaptive fuzzy-PID controller for pitch controlsystem

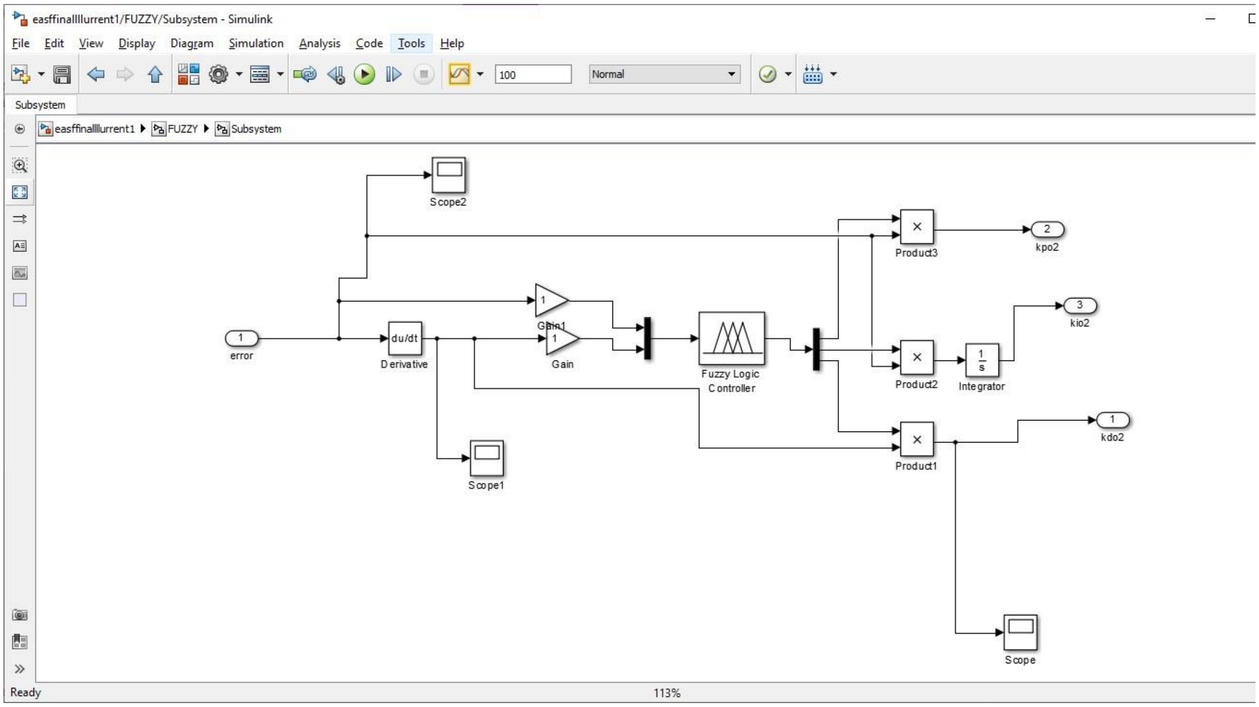


Figure 6.3.7 Subsystem- Fuzzy Controller

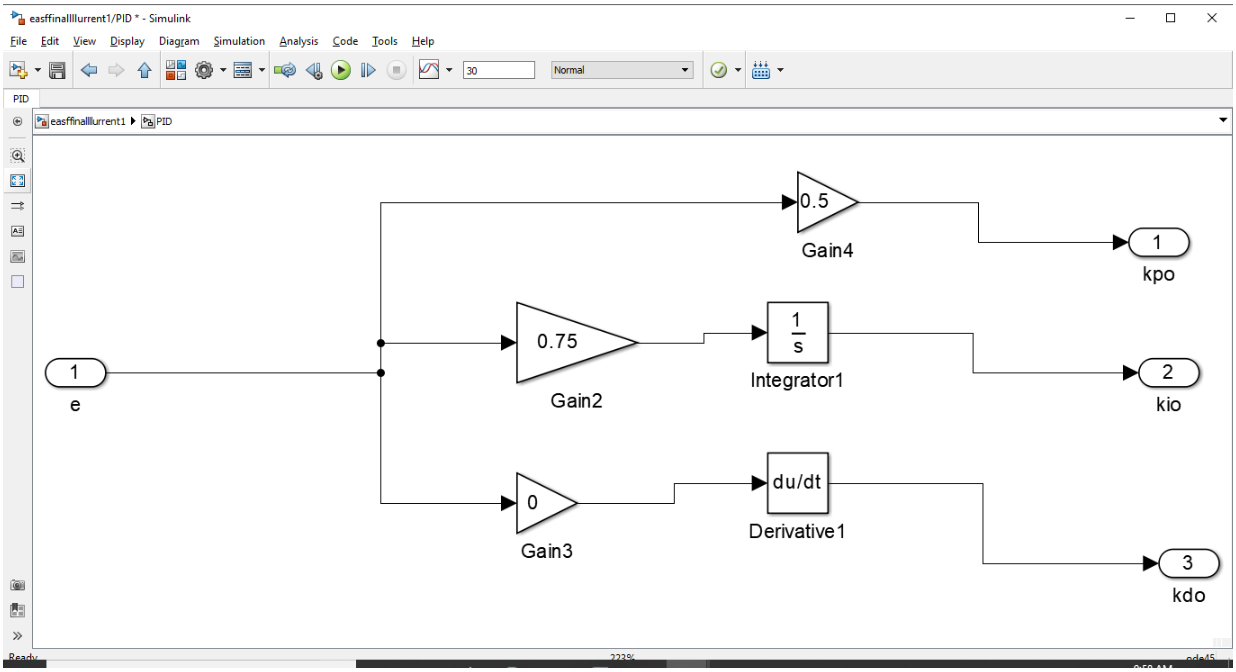


Figure 6.3.8 Subsystem- PID Controller

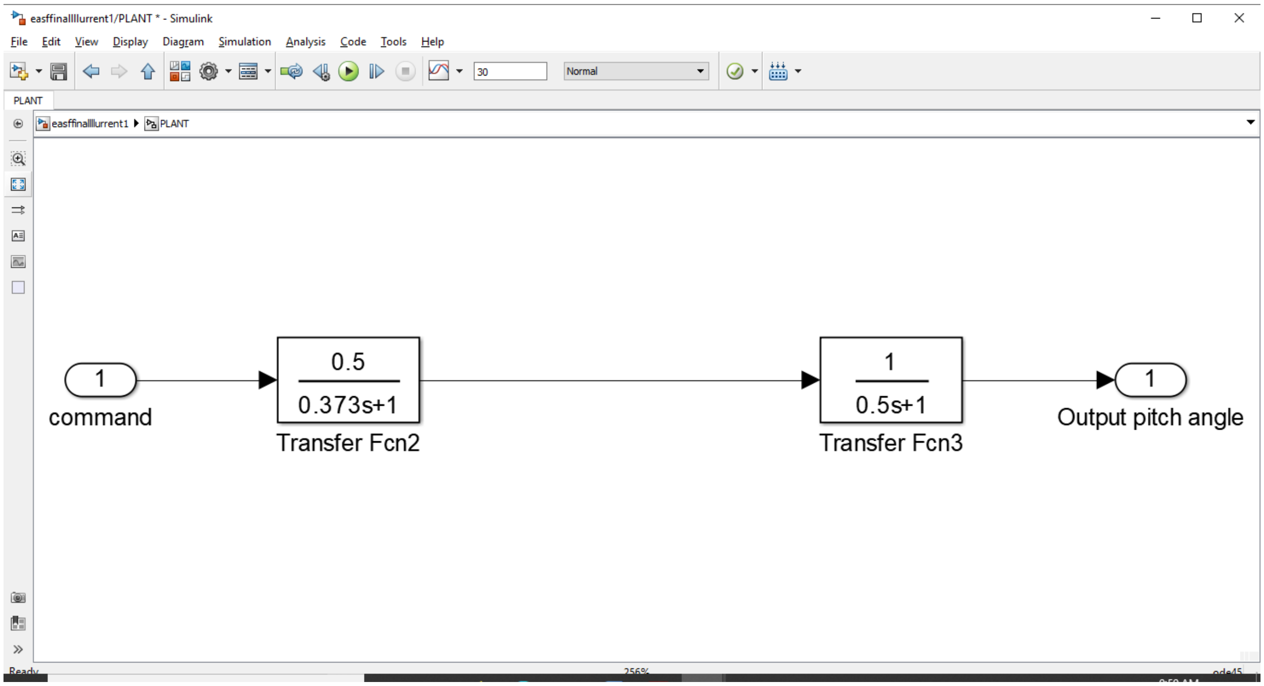
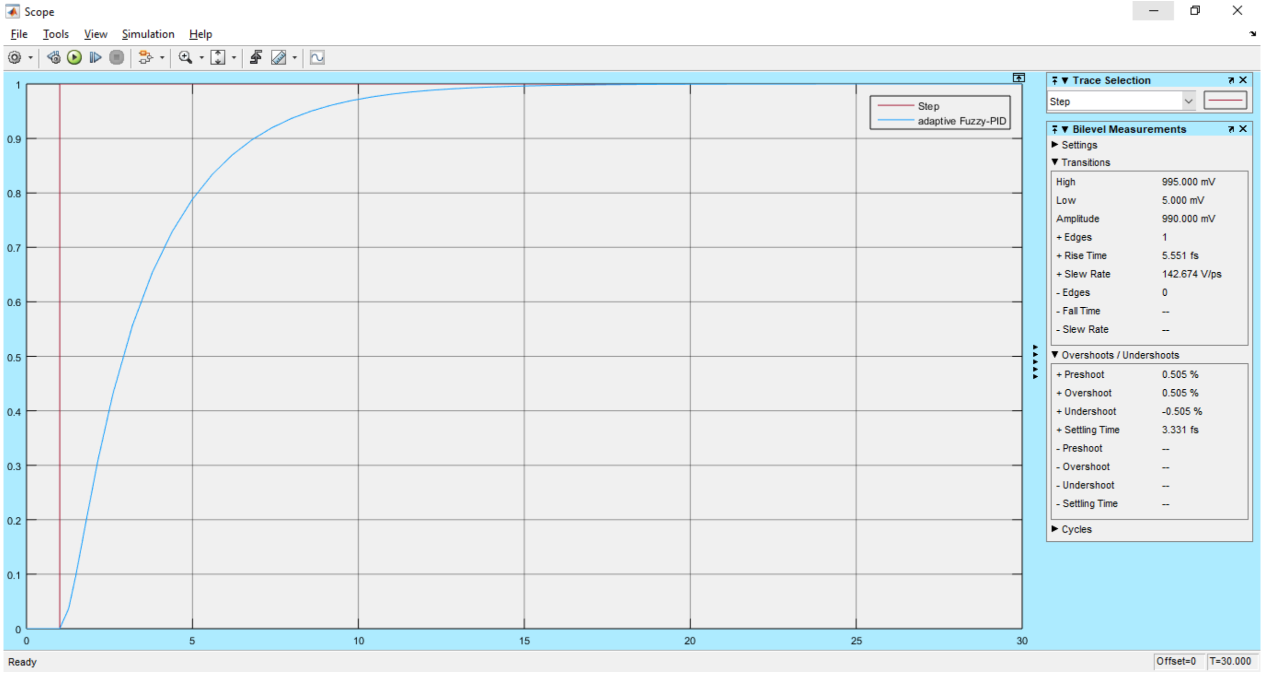


Figure 6.3.9 Subsystem of Plant

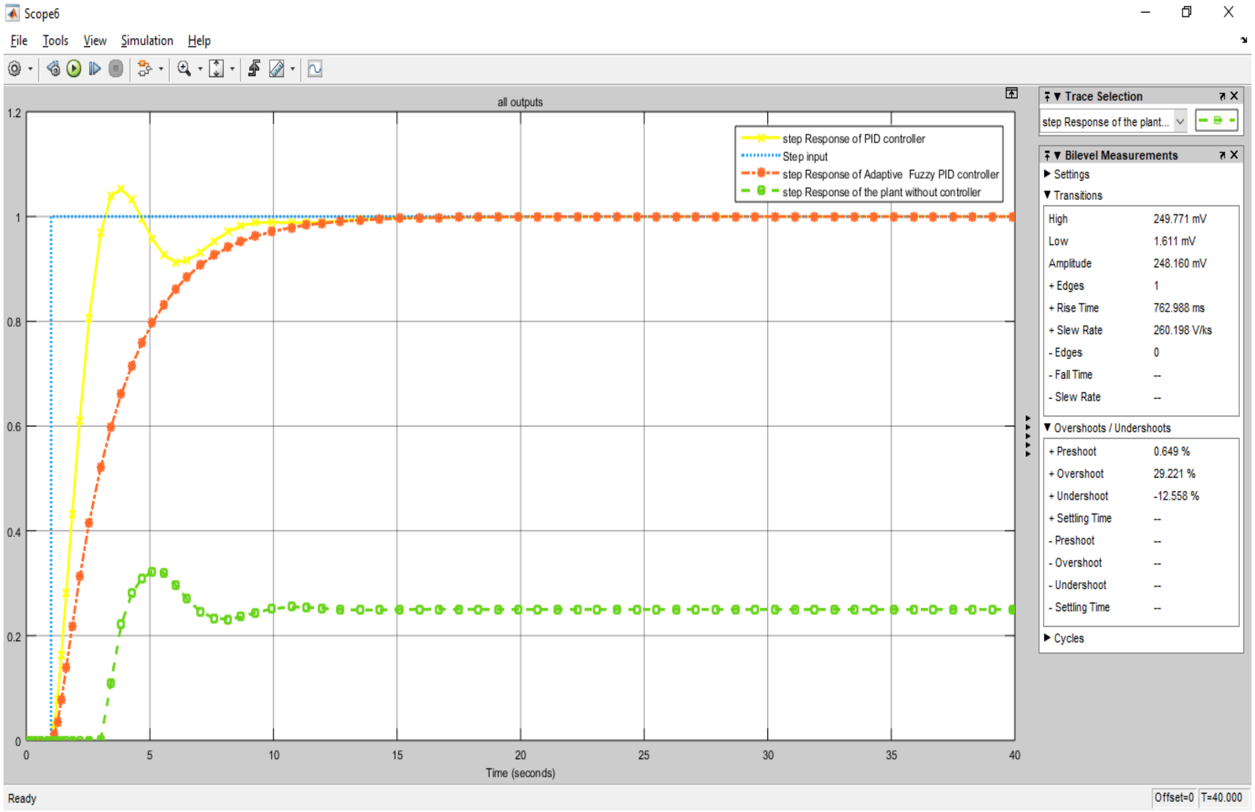


High	995.000 mV
Low	5.000 mV
Amplitude	990.000 mV
+ Edges	1
+ Rise Time	5.551 fs
+ Slew Rate	142.674 V/ps
- Edges	0
- Fall Time	--
- Slew Rate	--
+ Preshoot	0.505 %
+ Overshoot	0.505 %
+ Undershoot	-0.505 %
+ Settling Time	3.331 fs
- Preshoot	--
- Overshoot	--
- Undershoot	--
- Settling Time	--

Figure 6.3.10 The unit step response of wind turbine with Adaptive Fuzzy PID controller

Time Domain	With Adaptive Fuzzy-PID Controller
Delay Time(s)	2
Rise Time(s)	5.551
Settling Time(s)	3.331
Peak Overshoot	0.505%

Table 6.3.3 Time Domain Parameters for Unit step Input with Adaptive Fuzzy-PIDController



High	249.771 mV
Low	1.611 mV
Amplitude	248.160 mV
+ Edges	1
+ Rise Time	762.988 ms
+ Slew Rate	260.198 V/ks
- Edges	0
- Fall Time	--
- Slew Rate	--

+ Preshoot	0.649 %
+ Overshoot	29.221 %
+ Undershoot	-12.558 %
+ Settling Time	--
- Preshoot	--
- Overshoot	--
- Undershoot	--
- Settling Time	--

Figure 6.3.11 Unit step responses of Plant, Adaptive Fuzzy-PID and PID controller

In comparison to the PID controller, the Adaptive Fuzzy PID controller has the simplest unit step response of the turbine pitch system, as shown in the Tables.

The Adaptive Fuzzy PID delivers improved control for the pitch angle of the turbine system since the settling time is rapid (3.33sec) and the overshoot is exceptionally low (0.5 percent).

We may conclude from these results that intelligent procedures are superior to traditional control methods in terms of achieving pitch angle control and ensuring turbine output power stabilization.

The system's performance was improved by using fuzzy Turing PID parameters based on pitch angle control.

The adaptive fuzzy PID controller isn't tuned in the same way as traditional PID controllers are. It's constructed as a gaggle of control rules and thus the control signal is directly deduced from the knowledge base and therefore the fuzzy inference. Fuzzy controller parameters are tuned by starting from the equivalent values obtained for the optimum controller. this is often realized from this thesis.

The adaptive fuzzy-PID controller gives smooth motion for the pitch angle of the turbine blades as compared with the traditional PID method. Fuzzy tuning PID parameters gives an enhancement within the pitch angle response of the turbine as compared with using the PID controller only. Also, this intelligent method has suppressed the oscillation. PID controller emits to offer lower rise time and delay time but with overshoot adequate to 30.02% which cause defect within the system performance. Fuzzy tuning PID controller enhanced the transient response parameters as compared with conventional PID controller. during this paper, we developed the turbine pitch system mathematical model and simulated it with conventional PID and fuzzy adaptive PID controllers using MATLAB/Simulink. We compared the responses in terms of time-domain specifications for unit step input using conventional PID and fuzzy adaptive PID controllers. albeit , the PID controller produces the response with a lower rise time is 2.521s, has oscillations with a peak overshoot of 9.341%, which causes damage to the system performance. From the results, it are often observed that this controller can effectively suppress the oscillations and produces a smooth response. By using fuzzy adaptive PID controller, where the PID gains are adjusted by using symbolic logic concepts, the results showed that this design can effectively suppress the steady-state error, fast-rising time, quick settling time, and better stability. We conclude from the analysis that a fuzzy adaptive PID controller provides a relatively rapid response for a unit step input.This system is far superior in terms of understanding pitch control and ensuring the stability of turbine output power.As a result, managing power coefficient well and keeping generator output power fixed under wind speed is challenging, and for the nonlinear variable pitch system, fixed parameters PID controllers provide poor control performance.As a result, the Adaptive Fuzzy PID control methods are appropriate for a variable pitch system.

CHAPTER SEVEN

7.1 Conclusion

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It generates jobs, income, and economic benefits from a cost-competitive energy source; it diversifies the nation's energy collection; it's a clean, inexhaustible resource that doesn't require water; it has low operating costs; it's frequently integrated with minimal cost increases; and it's used in a variety of applications. That is the rationale for research efforts aimed at overcoming barriers to increased wind energy utilization.In terms of turbine pitch angle management and wind park layout optimization, the goal of this thesis is to make better use of wind energy.Wear occurs as a result of centrifugal, gravitational, and aerodynamic loads on a turbine's blades, resulting in a reduction in power output over the equipment's lifetime. Therefore, the necessity for a pitch angle control which will reduce the loading effect additionally to providing maximal power output. it's been tried to tackle those challenges within the sis work as discussed in the simulation part. The proposed Adaptive Fuzzy PID controller are often used alongside the other control aspects of the wind park to develop the general performance of the wind energy system. Wake effects within wind farms can significantly drop power product and increase the value of electricity. Herein, the designed wind park layout optimization method to attenuate a wake loss increases the facility production of wind farms. The wake minimization system wasn't tested in Laboratory and real implementation. However, the MATLAB\SIMULINK result shows the simplest placement of the turbine within the wind park within the x-y coordinate sort of each turbine. and therefore the arrangement of turbines is just visible within the simulation. By plotting optimal placement of a special number of WTs we could obtain a big total power of the wind park as compared to previous works. These enhancements can contribute to the adding capability of wind farms to offer consistent, low-cost, and effective wind energy systems.

7.2 Recommendation

During this chapter, several of the suggested method's major flaws should be examined in further detail.

Despite the fact that wake effects reduce wind speed, this isn't often the only drawback.
The air in the wake is not only slower, but it is also more turbulent, which can result in blade damage and significant maintenance expenses during the peak of the day.Although turbulence intensity as well as other losses should be the subject of multiple investigations, this issue is overlooked in this article.In addition to the typical goal of maximizing the facility produced, multi-objective optimization techniques could incorporate the goal of reducing turbulence intensity.A limit might also be used to prevent the turbulence intensity from becoming too high.In addition, the wind park's subsequent losses must be taken into account.Availability of turbines.Blade pollution, Electricity Line Loss, Weather Influence, and Air Density Difference, Control and Turbulence, Blade pollution , Electricity Line Loss, Weather Influence and Roughness.

7.3 Research limitations

The numerical optimization of wind farm layout and control method has been well-studied in this thesis.
There are, however, certain limitations that need be highlighted and addressed in future research.
The utilized wake model for wind farm optimization study has to be improved further.
The validity of the influence of wind speed change over non-flat terrain is evaluated and annual energy production (AEP) is not computed in the study while optimizing the wind farm layout considering terrain height fluctuations..

7.1 Future Work

In accordance with the aforementioned restrictions, the results of the optimized wind park architecture and control method are frequently directly evaluated using field tests; nonetheless, the following recommendations are for additional investigation.In wind park optimization studies, more complex wake models with improved accuracy of wake attributes are frequently used.Advanced optimization algorithms should be investigated in order to obtain higher-quality solutions with fewer function evaluations.A study of the effectiveness of various metaheuristic optimization approaches would be extremely beneficial due to the large number of techniques available.
These methods may provide a more effective solution.

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