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GENETIC ALGORITHM BASED APPROXIMATION OF WIND TURBINE SYSTEM STATE SUBJECTED TO BOUND WIND SPEED DISTURBANCES

By

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Abstract

Presently there is a growing energy demand usually covered by energy sources such as fossil fuel, coal and natural gas, which have been the basis for growth and development of the people since the beginning of 20th century. Wind is an intermittent generation resource and weather changes can cause large and rapid changes in output, system operators will need accurate and robust wind energy forecasting systems in the future.

Main defects in wind turbine are the emergence of an unanticipated outcome which are not considered during the design of the blade. The turbine is generally described by wind speed inputs and power output which represent the internal state of the wind turbine. Turbine disturbances can always exist in small or large scale depending on the environment of the system. The disturbances may be results of wrong measurement (unnecessary input insertion), or it can be the result of unnecessary (not optimal) power output, instrumental defect.

Using a mathematical model of non-linear systems such as model to analyze different possible disturbances by wind speed on the wind turbine power output with one interval for each parent in a given time. In each generation, the fitness of every individual in the power output is evaluated, multiple individuals are stochastically selected from the current power output (based on their fitness), and modified (recombined and possibly randomly mutated) to form a new power output. The new power output is then used in the next iteration of the algorithm.

The aim of this paper is to design a genetic algorithm based system state approximation mechanism for the wind turbine for which disturbances are assumed to be random defects, whose values are in a known limited intervals.

Genetic algorithm approach is a proficient approach for modeling the power systems that inspired their design and proposes to find out best solutions of the problems with any mathematical equations.

Acknowledgements

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I would like to thank my wife, Aster Baye, for her contributions to this thesis work by discussing on my ideas and reading the drafts of this thesis, supporting me under any circumstances and being next to me every time I am in need.

Dedication

I dedicate this thesis to

- All my family for their love and support.
- Dr. Ing. Abebayehu Assefa - RIP

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Chapter One

1. Introduction

1.1 Background

The recurrence of wind as an important source of the world's energy must rank as one of the significant developments of the late 20th century. The beginning of the steam engine, followed by the emergence of other technologies for converting fossil fuels to useful energy, would seem to have forever relegated to irrelevance the role of the wind in energy generation. In fact, by the mid-1950s that appeared to be what had already happened. By the late 1960s, however, the first signs of a reversal could be discerned, and by the early 1990s it was becoming apparent that a fundamental reversal was underway. **[12]**

There are five main factors to know what was happening.

1. There was a need.
2. There was the potential.
3. There was the technological capacity.
4. A vision of a new way to use the wind
5. The political will to make it happen.

Wind power production intimately depends on wind speed with certain of time, which changes with weather conditions. If the variability in wind speed conditions is not properly assessed, power production efficiency and power network operating costs may increase. Therefore, an accurate assessment of the uncertainty associated to wind speed forecasting is critical for the safe, reliable and economic operation of current and future power networks.

Genetic algorithms belong to the class of evolutionary algorithms which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover. In a genetic algorithm, a population of strings (called chromosomes or the genotype of the genome), which encode candidate solutions (phenotypes) to an optimization problem, evolves to find out better solutions. **[9]**

A genetic algorithm based approximation of wind turbine for the estimation of wind turbine parameters on the basis of requirements of electrical power for the given range of wind velocity, power coefficient, Tip speed ration (λ) with respect to time, the simulation results shows that the algorithm works well and can be used for wind turbine power output. **[20]**

1.2 Statement of the Problem and Motivation

The main problems in wind turbine blade are the appearance of an unexpected results or power outputs which are not considered during the variation of speed and other external defect on the turbine. Even though there are many works done on blade identification both by analytical and intelligent methods, there are no specific works done which evaluated and proposed which of the genetic algorithm methods are more appropriate to the kind of problem mentioned above. The main goal of this thesis is to thoroughly investigate the variation of speed on the blade systems with respect to different randomly generated faults and to evaluate which of the genetic algorithm methods are more appropriate to these systems.

Wind turbine is an object in which variables of different kinds interact and produce observable signals that are usually called power outputs. The wind turbine is also affected by external stimulus. External signals such as wind speed that can be manipulated by the observer are called inputs. Others are called disturbances and can be divided into those directly measured and only observed through their influence on the output. Many problems in various fields are solved in a system-oriented framework. The output is related to the input by a certain relationship known as the system response. The wind turbine response usually can be modeled with a mathematical relationship between the system input and the system output **[14]**. Wind turbine disturbances are signals which affect a system in such a way that it misbehaves (fluctuates from its normal behavior).

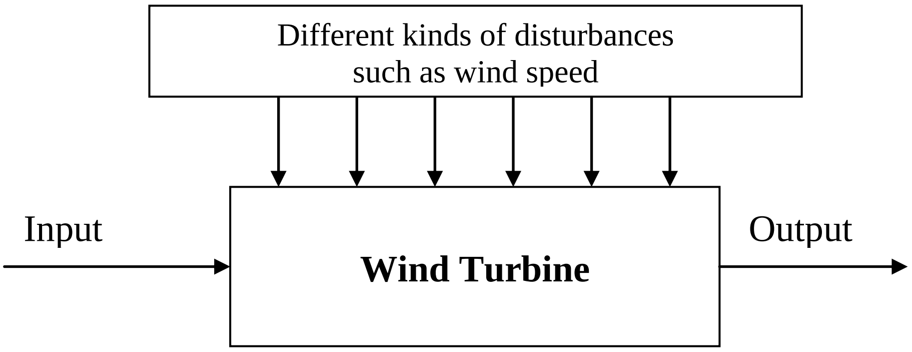


Figure 1.1 Wind energy systems

System identification is the process of developing or improving a mathematical representation of a physical system. System identification consists of two tasks. The first task is structural identification of the equations and the second one is an estimation of the model's parameters.

There are three types of identification in engineering structures [9]:

- Model based identification; (analytical)
- Experimental-data identification; and
- Intelligent method identification.

1.3 Objective of the Thesis

1.3.1 General Objective

The goal is to approximate the state of a wind turbine which is subject to wind speed generated bounded disturbances based on mathematical-model of the wind turbine using genetic algorithms.

1.3.2 Specific Objective

- The models of wind turbine power effects and evaluations utilize to obtain fair comparison with the results. Wind speed variation with respect to time among turbine blades can be approximated by a linear model
- Study different mathematical models of non-linear systems, their different identification method both analytical and intelligent system.
- Analyze the different possible disturbances on turbine and solutions for their eliminations
- Design genetic algorithm representing the turbine (encoding using genetic algorithm method)
- Evaluate the performance of different genetic algorithm approaches in solving the problem
- Suggest the optimum solution for the problem

1.4 Methodology

1.5.1 Literature survey in the area

In this section, different literatures in the area of the system which are subject to different randomly generated bounded wind speed disturbances based on mathematical-model of the wind turbine will be referred thoroughly.

1.5.2 Analysis and Modeling

Genetic Algorithms based approximations of wind turbine subjected to bounded disturbances such as wind speed disturbances are analyzed by simulation using the appropriate simulation environments such as MATLAB.

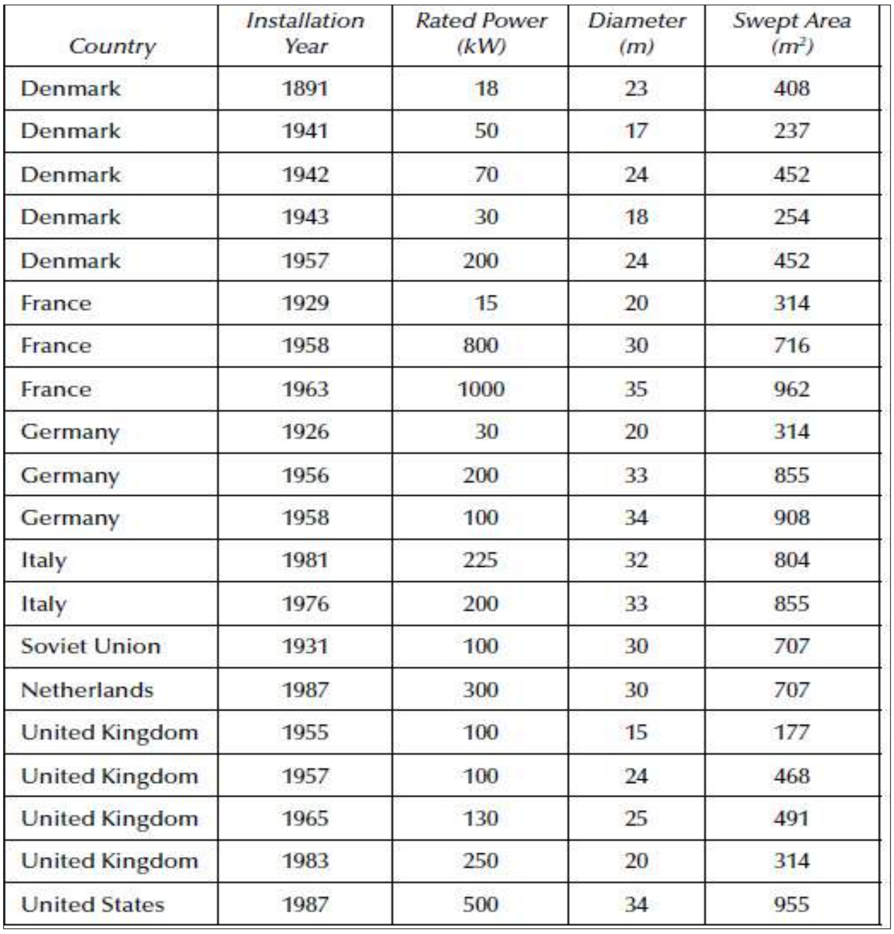
Chapter Two

2. Literature Review

2.1 Early Wind Turbine Development

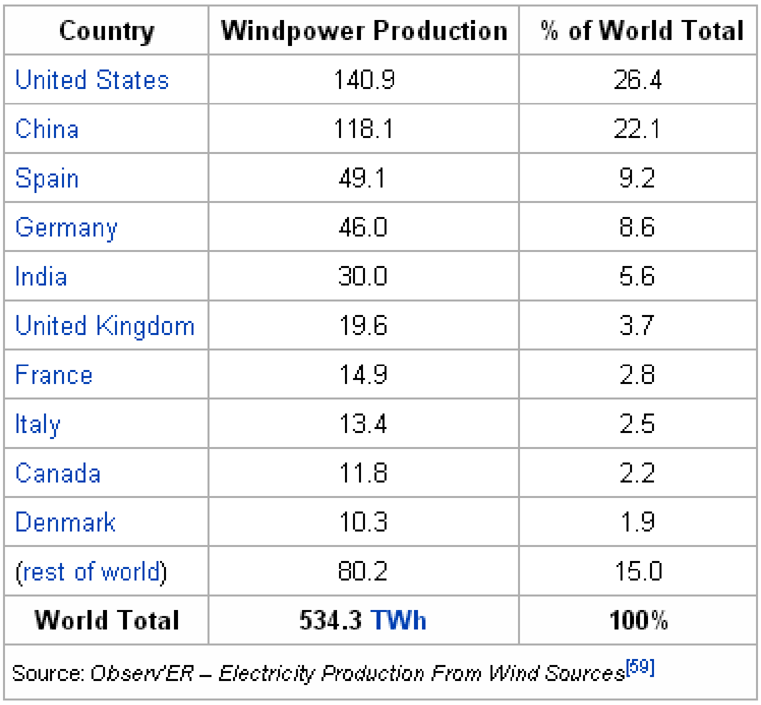
The author wishes to present a chronological development summary of wind turbines commencing from 1800. Published literature on renewable energy sources reveals that Denmark was the first country to install a 20-KW wind turbine as early as 1891 and it added four more wind turbines between 1941 and 1957. Denmark plans to add more wind turbine installations to meet 40% of its energy requirements by 2020. Table 2.1 summarizes data on wind turbine installations in various countries prior to 1990.

Table 2.1: Operating details of wind turbines installed before 1990



Country	Installation Year	Rated Power (kW)	Diameter (m)	Swept Area (m^2)
Denmark	1891	18	23	408
Denmark	1941	50	17	237
Denmark	1942	70	24	452
Denmark	1943	30	18	254
Denmark	1957	200	24	452
France	1929	15	20	314
France	1958	800	30	716
France	1963	1000	35	962
Germany	1926	30	20	314
Germany	1956	200	33	855
Germany	1958	100	34	908
Italy	1981	225	32	804
Italy	1976	200	33	855
Soviet Union	1931	100	30	707
Netherlands	1987	300	30	707
United Kingdom	1955	100	15	177
United Kingdom	1957	100	24	468
United Kingdom	1965	130	25	491
United Kingdom	1983	250	20	314
United States	1987	500	34	955

Table 2.2: Power output in different countries



Country	Windpower Production	% of World Total
United States	140.9	26.4
China	118.1	22.1
Spain	49.1	9.2
Germany	46.0	8.6
India	30.0	5.6
United Kingdom	19.6	3.7
France	14.9	2.8
Italy	13.4	2.5
Canada	11.8	2.2
Denmark	10.3	1.9
(rest of world)	80.2	15.0
World Total	**534.3 TWh**	**100%**

Source: *Observ'ER – Electricity Production From Wind Sources*[59]

2.2 Modern Wind Turbine

In modern wind turbines, the actual conversion process uses the basic aerodynamic force of lift to produce a net positive torque on a rotating shaft, resulting first in the production of mechanical power and then in its transformation to electricity in a generator. The output of a wind turbine is thus inherently fluctuating and non-dispatch able. Any system to which a wind turbine is connected must in some way take this variability into account. In larger networks, the wind turbine serves to reduce the total electrical load and thus results in a decrease in either the number of conventional generators being used or in the fuel use of those that are running. In smaller networks, there may be energy storage, backup generators, and some specialized control, systems. Today, the possibility of conveying electrical energy via power lines compensates to some extent for wind's inability to be transported. In the future, hydrogen-based energy systems may add to this possibility **[11].**

2.3 Current Status and Future Prospects of Wind Power Worldwide

The global wind energy development has increased rapidly in the past two decades. Global wind power markets have been for the past several years dominated by three major markets of European countries, North America and Asia. These three markets accounted for 86% of total installed capacity at the end of 2009. Although the cost varies between different countries, the trend everywhere is the same, hence the wind energy is becoming more economical and competitive. [**22].**

Twenty-one years have passed since the world's first offshore wind farm, Vindeby (5MW), was built in Denmark. Today, 4,620 MW of offshore wind power has been installed globally, representing about 2% of total installed wind power capacity. More than 90% of it is installed off northern Europe, in the North, Baltic and Irish Seas and the English Channel. According to the more ambitious projections, a total of 80 GW offshore wind could be installed by 2020 worldwide, with three quarters of this in Europe.

Offshore wind has a number of advantages, such as higher wind speeds and less turbulence than on land and fewer environmental constraints. Offshore is a relatively new technology with significant opportunities for cost reduction, technical innovations and 'revolutionary' developments which may change the face of renewable in some parts of the world [**10].**

2.4 Wind Turbine Technology Benefits and Installation Requirement

Renewable energy sources present many benefits. They offer clean, uninterrupted, environmental impact-free electrical energy at reasonable cost. Studies performed by the author indicate that wind and solar sources offer the cleanest and most cost-effective renewable energy. The studies further indicate that wind turbine technology is best suited for desalinating seawater, crop irrigation, and food production in coastal regions. Wind turbines are effective for desalination of water in coastal areas that lack fresh water. **[8 p3]**

Compared to other energy sources wind turbine technology offers affordability, pollution-free and maintenance-free operation. Major benefits of wind turbine technology can be briefly summarized as follows **[8]**:

- It saves substantial money on utility bills; users face no power shortages or failures as experienced by customers who depend on electrical utility grids.
- It delivers environmentally friendly and efficient electrical energy at lower cost, particularly, in areas where electrical grids are not available, for example in remote locations with difficult terrain features.
- Installation does not jeopardize the value of a home, office building, or commercial building. The installation can be easily undone and leaves no adverse visible effects at installation sites.
- The turbine does not require frequent or intermittent maintenance or employment of operations personnel; unlike steam and gas turbine-based alternator systems, no maintenance or operational costs are incurred.
- The technology essentially offers home-made electrical energy and off-grid living, which is not readily possible with other technologies **[11].**

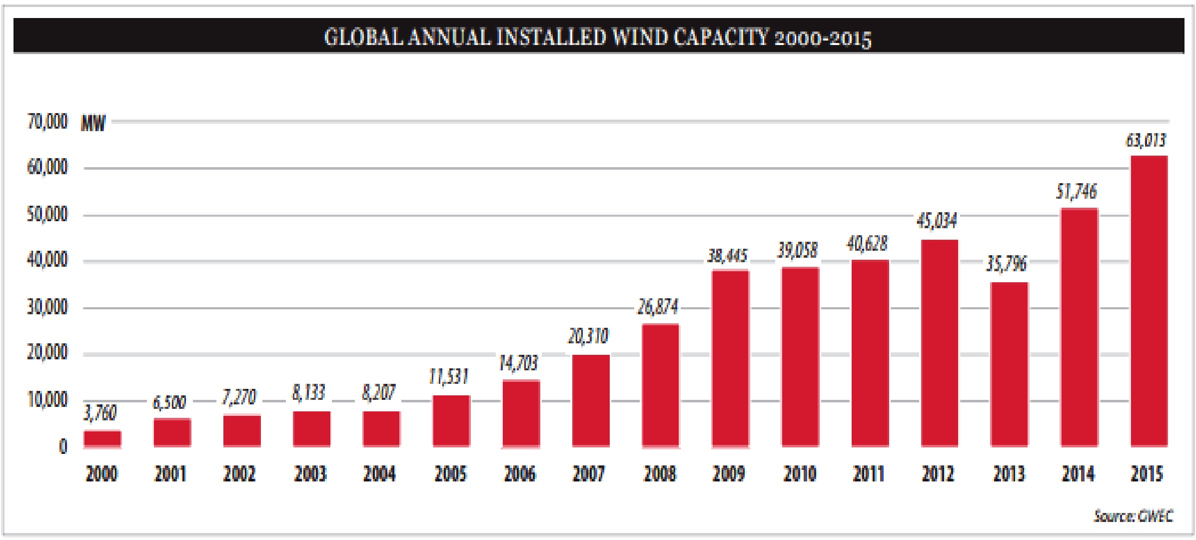
Wind turbines require unique installation specifications to operate with optimum efficiency. These strict installation requirements must not be characterized as major disadvantages. For example, wind turbine installers and designers carefully consider turbine sites and wind farm conditions. They must select optimum parameters for rotor blades, spacing between turbine units, height of the turbine and tower structures, and other conditions that will yield reliable, safe, and efficient operation with minimum maintenance and operation costs **[3].**

2.5 Annual Market Down; Return to Growth in 2014

The Global Wind Energy Council (GWEC) released its 2013 market statistics today, with cumulative global capacity reaching a total of 318,137 MW, an increase of nearly 200,000 MW in the past five years. However, the annual market dropped by almost 10 GW to 35,467 MW, attributable to the precipitous drop in US installations due to the policy gap created by the US Congress in 2012. While 2013 marked another difficult year for the industry with ‘only’ 12.5% cumulative growth, the prospects for 2014 and beyond look much brighter.

“China is a growth market again, which is good news for the industry. The government’s commitment to wind power has been reinforced once again by raising the official target for 2020 to 200 GW, and the industry has responded”, continued Sawyer.

India has a new national ‘Wind Mission’, Brazil booked 4.7 GW of new projects in 2013, and Mexico’s electricity sector reform is set to ignite the market in the coming years. While only chalking up 90 MW in installations in 2013 but after a slowdown in 2013, the wind industry set a new record for annual installations in 2014. Globally, 51,473 MW of new wind generating capacity was added, and the record-setting figure represents a 44% increase in the annual market. Total cumulative installations stood at 369,597 MW at the end of 2014. **[2]**



Source: GWEC

Figure 2.2: Global annual installed wind capacity

Country	End 2014	New 2015	Total End 2015
South Africa	570	483	1,053
Morocco	787	-	787
Egypt	610	-	610
Tunisia	245	-	245
Ethiopia	171	153	324
Jordan	2	117	119
Algeria, Cape Verde, Iran, Israel, Kenya, Libya, Nigeria	151	-	151

Table 2.3: Global installed wind power capacity (MW) - Africa & Middle East

2.6 Classification of Wind Turbine

Modern wind turbines are classified into two configurations: horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs), depending on rotor operating principles. The VAWT configuration is similar to an eggbeater design and employs the Darrieus model named for the famous French inventor. Regardless of classification, a wind turbine converts the kinetic energy of the wind into mechanical power that drives an alternating current (AC) induction generator to produce electricity.

2.6.1 Vertical Axis wind Turbines (VAWT)

The axis of rotation of vertical axis wind turbine (VAWT) is vertical to the ground and almost perpendicular to the wind direction as seen from Fig. 2.3. The VAWT can receive wind from any direction. Hence complicated yaw devices can be eliminated. The generator and the gearbox of such systems can be housed at the ground level, which makes the tower design simple and more economical. Moreover the maintenance of these turbines can be done at the ground level. For these systems, pitch control is not required when used for synchronous applications. The major disadvantage of some VAWT is that they are usually not self-starting. Additional mechanisms may be required to ‘push’ and start the turbine, once it is stopped. As the rotor completes its rotation, the blades have to pass through aerodynamically dead zones which will result in lowering the system efficiency. There are chances that the blades may run at dangerously high speeds causing the system to fail, if not controlled properly. Further, guy wires are required to support the tower structure which may pose practical difficulties [**19].**

Figure 2.3: Vertical axis wind turbine (VAWT)

2.6.2 Horizontal Axis Wind Turbines (HAWT)

Horizontal axis wind turbines (HAWT) have their axis of rotation horizontal to the ground and almost parallel to the wind stream (Fig. 2.4). Most of the commercial wind turbines fall under this category. Horizontal axis machines have some distinct advantages such as low cut-in wind speed and easy furling. In general, they show relatively high power coefficient. However, the generator and gearbox of these turbines are to be placed over the tower which makes its design more complex and expensive. Another disadvantage is the need for the tail or yaw drive to orient the turbine towards wind **[19].**

HAWTs with two or three blades are the most common. Wind blowing over the propeller blades causes the blades to "lift" and rotate at low speeds. Wind turbines using three blades are operated "upwind" with rotor blades facing into the wind. The tapering of rotor blades is selected to maximize the kinetic energy from the wind. Optimum wind turbine performance is strictly dependent on blade taper angle and the installation height of the turbine on the tower **[3].**

Figure 2.4: Horizontal axis wind turbines (HAWT)

2.6.3 Major Components of Horizontal Axis Wind Turbine

Today, the most common design of wind turbine is the horizontal axis wind turbine (HAWT). That is, the axis of rotation is parallel to the ground. HAWT rotors are usually classified according to the rotor orientation (upwind or downwind of the tower), hub design (rigid or teetering), rotor control (pitch vs. stall), number of blades (usually two or three blades), and how they are aligned with the wind (free yaw or active yaw).

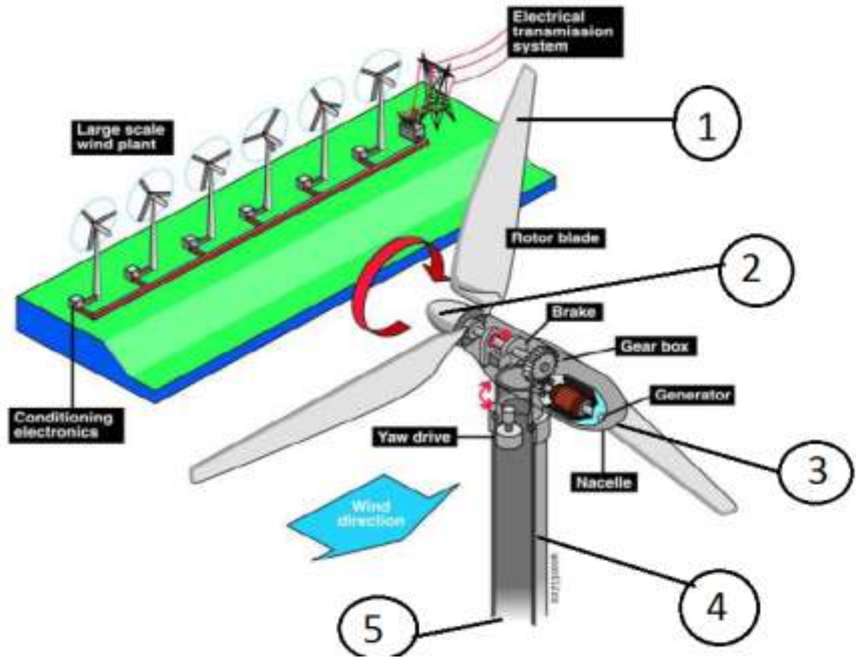


Figure 2.5: Major components of a HAWT and utility scale wind farm [Source: NREL, Wind Powering America, Presented by Tony Jimenez, 4 November 2008]

1. **Rotor blade**
2. **Hub**
3. **Nacelle**
4. **Tower**
5. **Foundation**

The principal subsystems of a typical horizontal axis wind turbine are including:

- The rotor, consisting of the blades and the supporting hub
- The drive train, which includes the rotating parts of the wind turbine (exclusive of the rotor); it usually consists of shafts, gearbox, coupling, a mechanical brake, and the generator

- The nacelle and main frame, including wind turbine housing, bedplate, and the yaw system The tower and the foundation
- The machine controls
- The balance of the electrical system, including cables, switchgear, transformers, and possibly electronic power converters

The main options in wind machine design and construction include:

- Number of blades (commonly two or three)
- Rotor orientation: downwind or upwind of tower
- Blade material, construction method, and profile
- Hub design: rigid, teetering or hinged
- Power control via aerodynamic control (stall control) or variable pitch blades (pitch control)
- Fixed or variable rotor speed
- Orientation by self-aligning action (free yaw), or direct control (active yawl Synchronous or induction generator, Gearbox or direct drive generator

I. Rotor

The rotor consists of the hub and blades of the wind turbine. These are often considered to be its most important components from both a performance and overall cost standpoint. Most turbines today have upwind rotors with three blades. There are some downwind rotors and a few designs with two blades.

II. Driven train

The driven train consists of the rotating parts of the wind turbine. These typically include a low-speed shaft (on the rotor side), a gearbox, and a high-speed shaft (on the generator side). Other drive train components include the support bearings, one or more couplings, a brake, and the rotating parts of the generator. The purpose of the gearbox is to speed up the rate of rotation of the rotor from a low value (tens of rpm) to a rate suitable for driving a standard generator (hundreds or thousands of rpm). Two types of gearboxes are used in wind turbines: parallel shaft and planetary. For larger machines (over approximately 500 kW), the weight and size advantages of planetary gearboxes become more pronounced. Some wind turbine designs use specially designed, low-speed generators requiring no gearbox.

III. Generator

Nearly all wind turbines use either induction or synchronous generators. Both of these designs entail a constant or near-constant rotational speed of the generator when the generator is directly connected to a utility network. The majority of wind turbines installed in grid connected applications use induction generators. An induction generator operates within a narrow range of speeds slightly higher than its synchronous speed (a four-pole generator operating in a 50 or 60 Hz grid has a synchronous speed of 1800 rpm). The main advantage of induction generators is that they are rugged, inexpensive, and easy to connect to an electrical network.

An option for electrical power generation involves the use of a variable speed wind turbine. There are a number of benefits that such a system offers, including the reduction of wear and tear on the wind turbine and potential operation of the wind turbine at maximum efficiency over a wind range of wind speeds, yielding increased energy capture. Although there are a large number of potential hardware options for variable speed operation of wind turbines, power electronic components are used in most variable speed machines currently being designed. When used with suitable power electronic converters, either synchronous or induction generators can run at variable speed.

IV. Nacelle and yaw system

The main frame provides for the mounting and proper alignment of the drive train components. The nacelle cover protects the contents from the weather. A yaw orientation system is required to keep the rotor shaft properly aligned with the wind. The primary component is a large bearing that connects the main frame to the tower. An active yaw drive, generally used with an upwind wind turbine, contains one or more yaw motors, each of which drives a pinion gear against a bull gear attached to the yaw bearing. This mechanism is controlled by an automatic yaw control system with its wind direction sensor usually mounted on the nacelle of the wind turbine. Sometimes yaw brakes are used with this type of design to hold the nacelle in position, free yaw systems (meaning that they can self-align with the wind) are commonly used on downwind wind machines.

V. The principal

Types of tower design currently in use are the free standing type using steel tubes, lattice (or truss) towers, and concrete towers. For smaller turbines, guyed towers are also used. Tower height is typically 1 to 1.5 times the rotor diameter, but in any case is normally at least 20 m. Tower selection is greatly influenced by the characteristics of the site. The stiffness of the tower is a major factor in wind turbine system dynamics because of the possibility of coupled vibrations between the rotor and tower.

VI. Controls

The control system for a wind turbine is important with respect to both machine operation and power production. A wind turbine control system includes the following components:

- Sensors - speed, position, flow, temperature, current, voltage, etc.
- Controllers - mechanical mechanisms, electrical circuits, and computers
- Power amplifiers - switches, electrical amplifiers, hydraulic pumps and valves
- Actuators - motors, pistons, magnets, and solenoids

GA has been successfully applied to aerodynamic, aeroacoustics, and aero structural optimization problems, both generally, and in the context of HAWTs.

G.B. Eke and , J.I. Onyewudiala are considered optimizing the blade of wind turbines with respect to maximizing the energy yield of a wind turbine. The design variables are the shape parameters comprising the chord, the twist and the relative thickness of the blade. Genetic algorithm was used to illustrate the optimization technique; two wind turbines of different sizes are subjected to analysis.

Xiaomin Chen did dissertation for Doctor of Philosophy, a numerical optimization method called Genetic Algorithm (GA) is applied to address the shape optimization of wind turbine airfoils and blades. In recent years, the airfoil sections with blunt trailing edge (called flat back airfoils) have been proposed for the inboard regions of large wind turbine blades because they provide several structural and aerodynamic performance advantages.

He employed DU 91-W2-250, FX 66-S196-V1, NACA 64421, and Flat back series of airfoils and compare their performance with S809 airfoil used in NREL Phase II and III wind turbines; the lift and drag coefficient data for these airfoils sections are available. The output power of the turbine is calculated using these airfoil section blades for a given B and λ and is compared with the original Phases. It is shown that by a suitable choice of airfoil section of HAWT blade, the power generated by the turbine can be significantly increased. Parametric studies are also conducted by varying the turbine diameter. In addition, a simplified dynamic inflow model is integrated into the BEM theory. It is shown that the improved BEM theory has superior performance in capturing the instantaneous behavior of wind turbines due to the existence of wind turbine wake or temporal variations in wind velocity.

Mario Graff, Rafael Pe˜na and Aurelio Medina did the application of genetic programming to the problem of time series forecasting. This forecast technique is applied to wind speed time series. The results obtained from the forecasting are used to determine the power generation capacity of a fixed-speed wind turbine, which includes a squirrel cage induction generator. The forecast values obtained with the genetic programming are compared against the original time series data in order to show the precision of this forecast technique.

Pankaj Jain, P.B.Sharma, V.K. Sethi and Mukesh Pandey presented a genetic algorithm based optimization technique for the estimation of wind turbine parameters on the basis of requirements of electrical power, rotating speed, and chord area for the given range of wind velocity, blade radius, Tip speed ration (TSR), etc. the simulation results shows that the algorithm works well and can be used for wind turbine design. Furthermore they also analyzed the characteristics of the wind turbine with the specifications calculated by genetic algorithm.

Chapter Three

3. Genetic Algorithm and Basic Systems

3.1 Genetic Algorithm

GAs is good at finding “acceptably good” solutions to problems “acceptably quickly“. Where specialized techniques exist for solving particular problems, they are likely to outperform GAs in both speed and accuracy of the final result. Genetic algorithms emulate the mechanics of natural selection by a process of randomized data exchange. In this way they are able to solve ranges of difficult problems which cannot be tackled by other approaches. The fact that they are able to search in a randomized, yet directed manner, allows them to reproduce some of the innovative (ingenious) capabilities of natural systems. Because genetic algorithms were inspired by the behavior of natural systems, the terminology used to describe them is a mix from both biological and computer fields. A genetic algorithm manipulates strings of information, usually called chromosomes. These encode potential solutions to a given problem. Chromosomes are evaluated and assigned a score (fitness value) in terms of how well they solve the given problem according to criteria defined by the programmer.

These fitness values are used as a probability of survival during a round of reproduction. New chromosomes are produced by combining two (or more) parent chromosomes. This process is designed to lead to a succession of fitter offspring, each encoding better solutions, until an acceptably good solution is found.

In general, the GAs is a stochastic global search method that mimics the metaphor (concept of understanding one thing in terms of another) of natural biological evolution. GAs operates on a population of potential solutions applying the principle of survival of the fittest to produce (hopefully) better and better approximations to a solution. At each generation, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals that they were created from, just as in natural adaptation. Individuals, or current approximations, are encoded as strings, chromosomes, composed over some alphabet(s), so that the genotypes (chromosome values) are uniquely mapped onto the decision variable (phenotypic) domain. **[7]**

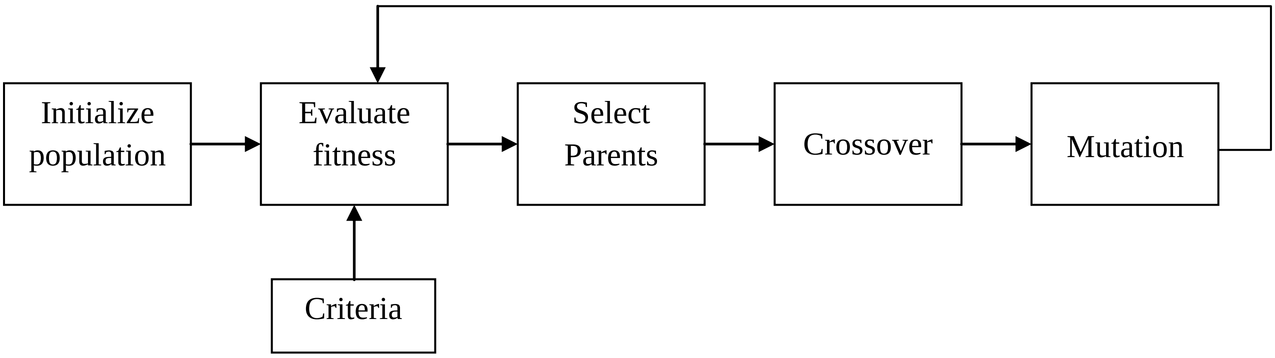


Figure 3.1 Major component of Genetic Algorithm

3.2 Basic Principle of Genetic Algorithm

"GAs" have at least the following elements in common:-

- Initial population (Populations of chromosomes)
- Encoding(Population Representation to biological term)
- Fitness function and selection according to fitness
- Reproduction (to produce new offspring)
- Stopping criteria

Initial population (Populations of chromosomes): The major questions to consider are, firstly, the size of the population.

Initialize population by applying random variations to an initial rotor.

(3.1)

Encoding: Before a GAs can be run, a suitable coding for the problem must be selected. GAs operates on a number of potential solutions, called a population, consisting of some encoding of the parameter set simultaneously.

3.3 Encoding Methods

3.3.1 Binary encoding

The most commonly used representation of chromosomes in the GA is that of the single-level binary string

- Chromosome A: 0101101100010011
- Chromosome B: 1011010110110101

3.3.2 Permutation encoding

In permutation encoding, every chromosome is a string of numbers, which represents number in a sequence.

- Chromosome A: 8549102367
- Chromosome B: 9102438576

3.3.3 Direct value encoding

It can be used in problems where some difficult values such as real numbers are used. Use of binary encoding for this type of problems would be very challenging. In value encoding, every chromosome is a string of some values. Values can be anything connected to problem, form numbers, real numbers or singes to some complicated objects.

Chromosome A:	[red], [black], [blue], [yellow], [red], [green]
Chromosome B:	[1.876, 3.982, 9.128, 6.834, 4.116, 2.192]
Chromosome C:	ABCKDEIFGHNWLSWWEKPOIKNGVCI

Binary coded in GAs is less efficient when applied to multidimensional, high-precision or continuous problems. The reason is that the bit-strings can develop very long and the search space blows up compared to real-coded.

3.3.4 Fitness Function

A fitness function must be formulated for each problem to be solved. Given a particular chromosome, the fitness function returns a single numerical “fitness “or “figure of merit” which is supposed to be proportional to the “utility” or “ability” of the individual which that chromosome represents **[1] [7].**

3.4 Types of selection

I. **Roulette:** A chromosome getting selected is proportional to its fitness (or rank).

II. **Tournament:** A selection operator which uses roulette selection N times to produce a tournament subset of chromosomes. This method of selection applies addition selective pressure over plain roulette selection.

III. **Top Percent:** Selects a chromosome from the top N percent of the population as specified by the user.

IV. **Best:** Selects the best chromosome (as determined by fitness). If there are two or more chromosomes with the same best fitness, one of them is chosen randomly.

V. **Random**: Randomly selects a chromosome from the population.

These operators select chromosomes in the population for reproduction. The fitter the chromosome, the more times it is likely to be selected to reproduce **[13]**.

3.5 Reproduction

The reproductive phase of the GAs, individuals are selected from the population recombined, and producing offspring which will comprise the next generation. The most basic forms of these Genetic operators are as follows.

3.6 Crossover

The algorithm exchanges the last k-bits between pairs of solution in the mating pool according to some probability (P_{cross}) to produce two candidate solutions for the next iteration, if the solutions are binary coded. Crossover is a genetic operator that combines (mates) two chromosomes (parents) to produce a new chromosome (offspring). The idea behind crossover is that the new chromosome may be better than both of the parents, if it takes the best characteristics from each of the parents **[7] [13].**

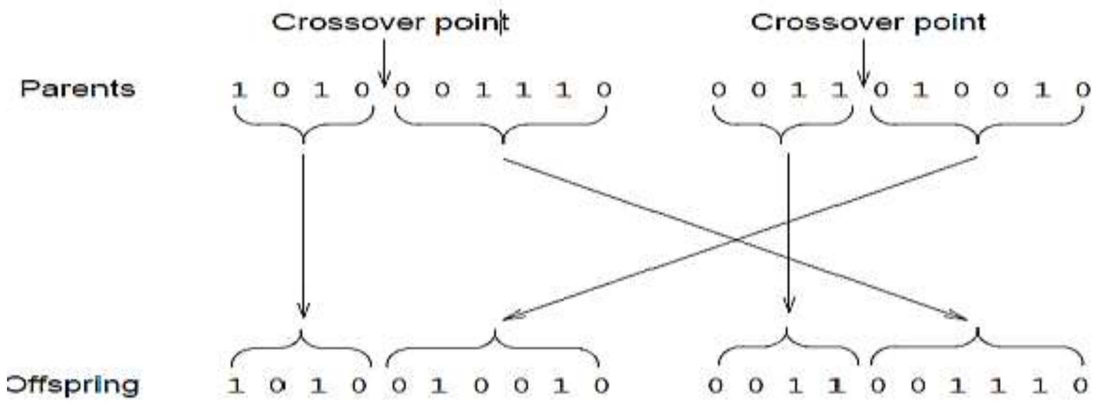


Figure 3.2 **Real-coded crossover operators**

Some genetic crossover operators for problems are coded by real numbers **[15]**.

3.6.1 Types of Crossover

- Mid-Point Crossover
- Linear crossover
- Heuristic crossover
- Simple crossover

Mid-Point Crossover

There are two parents such as X and Y represent a floating point number:

- Parent 1: X
- Parent 2: Y

Linear crossover

1. Select two parents $X^{(t)}$ and $Y^{(t)}$ from a parent pool
2. Generate pair offspring $X^{(t+1)}$ and $Y^{(t+1)}$ as follows:

a. Define three temporary vectors

$Z=(z_1,z_2,\ldots\ldots z_n)$, $V=(v_1,v_2,\ldots\ldots v_n)$ and $W=(w_1,w_2,\ldots\ldots w_n)$ as follows

for i = 1 to n do

– – – – – –

End do

b. select the best two vectors from { Z, V, W} which are offspring's X(t+1) and Y(t+1)

Heuristic Crossover

A crossover operator that uses the fitness values of the two parent chromosomes to determine the direction of the search. The offspring are created according to the following equations:

Where: Best Parent Worst Parent r = a random number (0, 1).

1. Select two parents $X^{(t)}$ and $Y^{(t)}$ from a parent pool
2. Generate a single offspring $X^{(t+1)}$ as follows:

a) Uniform probability selected randomly a real number α ε<0, 1>

if then

Else if

End if

where:

= the fitness function

Simple Crossover

A crossover operator that linearly combines two parent chromosome vectors to produce two new offspring according to the following equations

where:

P_1 = Parent One

P_2 = Parent Two

a= a random weighting factor, chosen before crossover operation

1. Select two parents $X^{(t)}$ and $Y^{(t)}$ from a parent pool
2. Generate pair offspring $X^{(t+1)}$ and $Y^{(t+1)}$ as follows:
    a. Randomly select crossover point h ε { 1, …..,n} Where n is the chromosome length
    b. Uniform probability select randomly a real number α ε<0,1>

```
fori=1 to h do
          –
          –
end do
for        to n do
End do
```

3.7 Mutation

Crossover is the process by which sections of the genomes of the two parents are switched in order to produce unique offspring. Every gene in the genome consists of eight binary digits, where a gene represents one numerical value used to define the shape of the rotor, for example, and the y-location of a Bezier curve control point. For each gene, crossover operates. Two endpoints in the gene, of values between 1 and 8, are randomly selected **[10].**

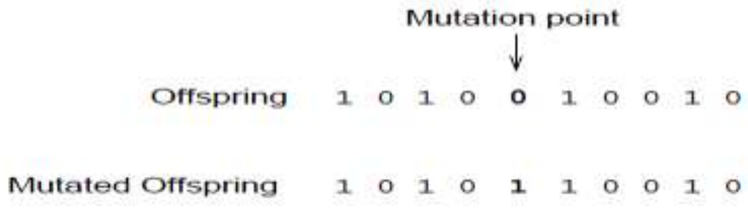


Figure 3.3 Real-coded mutation operators

3.7.1 Types of Mutation

- Uniform Mutation
- Boundary Mutation

Uniform Mutation

```
Select set of parents {$X_1$ (t) ,………. $X_n$ (t) number of parents} from the actual population P(t)
    Do crossover and produce offspring's
    {$X_1^{(t+1)}$ , ……….. $X^{(t+1)}$}
    For j=1 to number of offspring's do
    If $R_{nd} \leq P_{um}$ then (mutate $X_j^{(t+1)}$)
With uniform probability randomly select mutation point k ε { 1, ..n} n – is chromosome length from the interval <$X_k^l$ , $X_k^u$ >
                $X_{jk}^{(t+1)} \leftarrow\text{--}\alpha$
            End if
            End do
```

where: R_{nd}= randomly selected real number with uniform probability from the interval (0,1)

P_{um} = a uniform mutation probability.

Boundary Mutation

```
Select set of parents {$X_1$ (t),…., X (t) Number of parents} from the actual population p(t)
    Do crossover and produce offspring's
    For j=1 to no. of offspring's do

If $R_{nd} \leq P_{bm}$then (mutate $X_j$ (t+1)), else no change of any chromosomes in the offspringWith uniform probability select mutation point k ε {1, …….,n}
            If $R_{nd}$<0.5 then
                $X_{jk}^{(t+1)} \leftarrow$-- $X_k^l$
            Else
                $X_{jk}^{(t+1)} \leftarrow$-- $X_k^u$
            End if
        End if
        End do
```

where: P_{bm}= The probability of boundary mutation

3.8 Basic Steps of Genetic Algorithm

1. [Start]: Generate random population of n chromosomes (suitable solutions for the problem) (chromosome (individual) representation)
2. [Fitness]: Evaluate the fitness f(x) of each chromosome x in the population (evaluation objective function) P(G+1)
3. [New population]: Create a new population by repeating the following steps until the new population is complete

    i. [Selection]: Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected)
    ii. [Crossover]: With a crossover probability cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents.
    iii. [Mutation]: With a mutation probability mutates new offspring at each locus (position in chromosome).
    iv. [Accepting]: Place new offspring in a new population

4. [Replace]: Use new generated population for a further run of algorithm
5. [Test]: If the end condition is satisfied, stop, and return the best solution in current population
6. [Loop]: Go to step 2. **[10]**

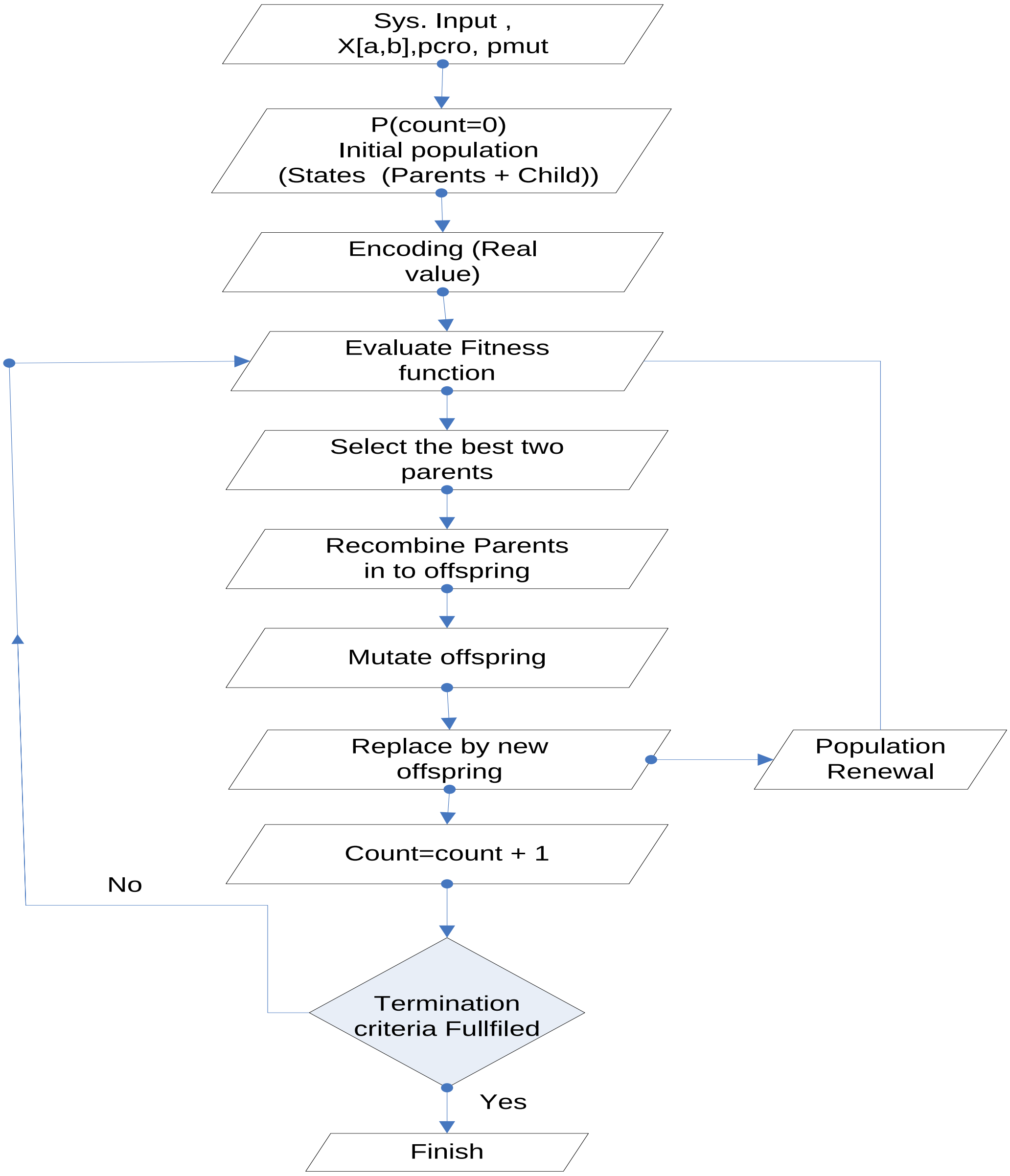


Figure 3.4 A general flow chart

Chapter Four

4. Problem Formulation

4.1 Airfoil Theory

Air flows more quickly over the top surface of an airfoil than the bottom surface, resulting in a pressure difference and lift. The lift on an airfoil is several times the drag. As the angle of attack ‘α’ increases, lift increases until stall (a situation during which an angle of attack becomes so large that the air flow no longer flow smoothly, or laminar, across the profile) occurs.

4.2 Rotor Blade Designs

The rotor blades are the foremost visible part of the wind turbine, and represent the forefront of aerodynamic engineering. The steady mechanical stress due to centrifugal forces and fatigue under continuous vibrations make the blade design the weakest mechanical link in the system. Extensive design effort is needed to avoid premature fatigue failure of the blades **[16].**

The rotor blades of current wind turbines reflect the different compromises between the optimum aerodynamic shape, the requirements of strength and stiffness and concessions to economic manufacturing. Naturally, blade material also plays a significant part in the design. The optimum aerodynamic shape can be approximated much better by design concepts involving glass-fiber reinforced plastic (GFRP) than by rotor blades made entirely of metal as in some earlier experimental turbines. Nearly all rotor blades have a trapezoidal shape which more or less approximates the optimum aerodynamic contour. The aspect ratio is remarkably high compared to aircrafts wings where only the wings of high-performance gliders are built with such high aspect ratios.

The existing thickness-to-chord ratios of the airfoils used must, therefore, be chosen with consideration of stiffness and strength aspects. In the outboard section of the rotor blades, which is of special interest from the aerodynamic point of view, a thickness ratio of between

12 - 15 % is usual. In the inner section, near the blade root, blade thickness is increased. In almost all cases, the blade plan form is chamfered at the root so that the airfoil section can converge into the circular cross-section of the hub flange.

The blades of the larger three-bladed rotors have a higher aspect ratio, both for rotors with pitch control and for limiting power by stall control. In most cases the selected tip-speed ratio is in the range of approximately 7 and thus near to the aerodynamic optimum. Another important criterion is the blade tip speed with respect to noise emission. The experience shows that tip speeds more than 70 m/s cause noise problems **[8].**

It can be seen that blades designed for optimum power production have an increasingly large chord and twist angle as one gets closer to the blade root. One consideration in blade design is the cost and difficulty of fabricating the blade. An optimum blade would be very difficult to manufacture at a reasonable cost, but the design provides insight into the blade shape that might be desired for a wind turbine.

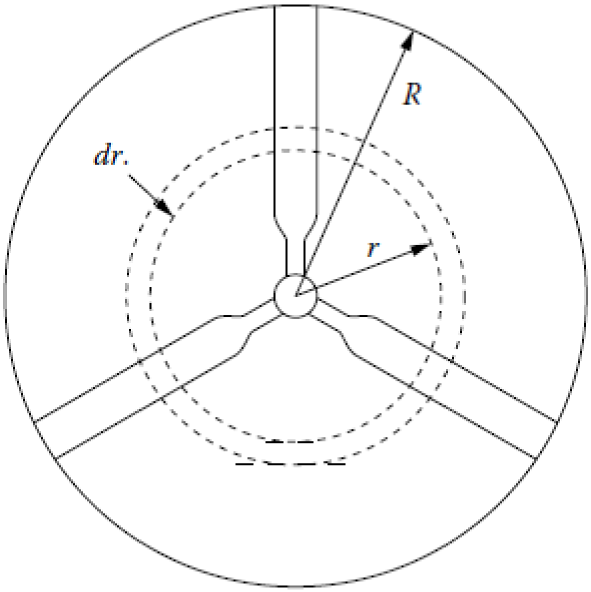


Figure 4.1 Wind turbine rotor configurations with three blades

4.3 Wind Speed and Power Output

Low wind speed means low energy capture; a wind turbine operation will not be cost-effective under such condition. A variable generator excitation control technique implemented in turbine design will realize significant improvement in the amount of wind energy capture and consequently higher wind turbine power output in low wind speed environments and also improves the aerodynamic rotor control to ensure safety and reliability of the entire system. Turbine efficiency depends on the number of blades used and the blade efficiency. Blade performance is a function of flow angle, wind speed, blade radius, angle of attack, blade pitch angle and axial and longitudinal interference factors.

The turbines that dominate the current markets operate at high tip speed-to-wind speed ratios ranging typically from 5 to 7 and utilize three-bladed rotors with rotational speeds of 10 to 30 rpm. As the wind speed increases to the cut-in speed the turbine begins to operate. Between the cut-in and the rated wind speeds the turbine takes all the power it can from the wind. Above the rated wind speed and below cut-out the turbine maintains a constant power output, called the **rated power** which is lower than the actual available power in the wind but the maximum that the wind turbine is capable of producing.

The tower height for HAWTs is extremely important because wind speed increases with the height above the ground. Rotor diameter is equally important because it determines the area needed to meet specific output power level. The power output performance of a HAWT can be optimized by selecting a ratio between the rotor diameter and the hub height very close to unity. The rated power output of a wind turbine is the maximum power allowed for the installed electrical generator **[3].**

The wind speed passing through the turbine rotor is considered uniform as V, with its value as V_1 (upwind), and as V_2 (downwind) at a distance from the rotor. Extraction of mechanical energy by the rotor occurs by reducing the kinetic energy of the air stream from upwind to downwind, or simply applying a braking action on the wind.

The kinetic energy in air of mass m moving with speed V is given by the following expression:

$$\text{Kinetic energy} = - \tag{4.1}$$

$$V_2 < V_1$$

Consequently the air stream cross sectional area increases from upstream of the turbine to the downstream location,

$$A_1 < A_2$$

If the air stream is considered as a case of incompressible flow, the conservation of mass or continuity equation can be written as:

The mass flow rate is a constant along the wind stream. Continuing with the derivation, Euler’s Theorem gives the force exerted by the wind on the rotor as:

Where

The power content of the wind stream is:

The power as the rate of change in kinetic energy from upstream to downstream using the continuity equation is given by:

Equating the above two expressions for the power P in Eqns.

The wind velocity at the rotor may be taken as the average of the upstream and downstream wind velocities. It also implies that the turbine must act as a brake, reducing the wind speed from V_1 to V_2, but not totally reducing it to $V = 0$, at which point the equation is no longer valid. To extract energy from the wind stream, its flow must be maintained and not totally stopped.

The last result lets new expressions to be written for the force F and power P in terms of the upstream and downstream velocities by substituting for the value of V as:

The “downstream velocity factor,” or “interference factor,” λ or tip speed as the ratio of the downstream speed v_2 to the upstream speed v_1 as:

—

The extractable power P by the blades in terms of the interference factor (Tip Speed ratio) “λ”. The most important observation pertaining to wind power production is that the extractable power from the wind is proportional to the cube of the upstream wind speed and is a function of the interference factor λ (Tip Speed Ratio).

–

The power extracted by the blades is

P = –

where:

C_P= The fraction of the upstream wind power that is extracted by the rotor blades and fed to the electrical generator. The remaining power is dissipated in the downstream wind, i.e. C_p is called the power coefficient of the rotor or the rotor efficiency.

The performance coefficient or efficiency is the dimensionless ratio of the extractable power, P to the kinetic power, P_k available in the undisturbed stream:

— –

–

–

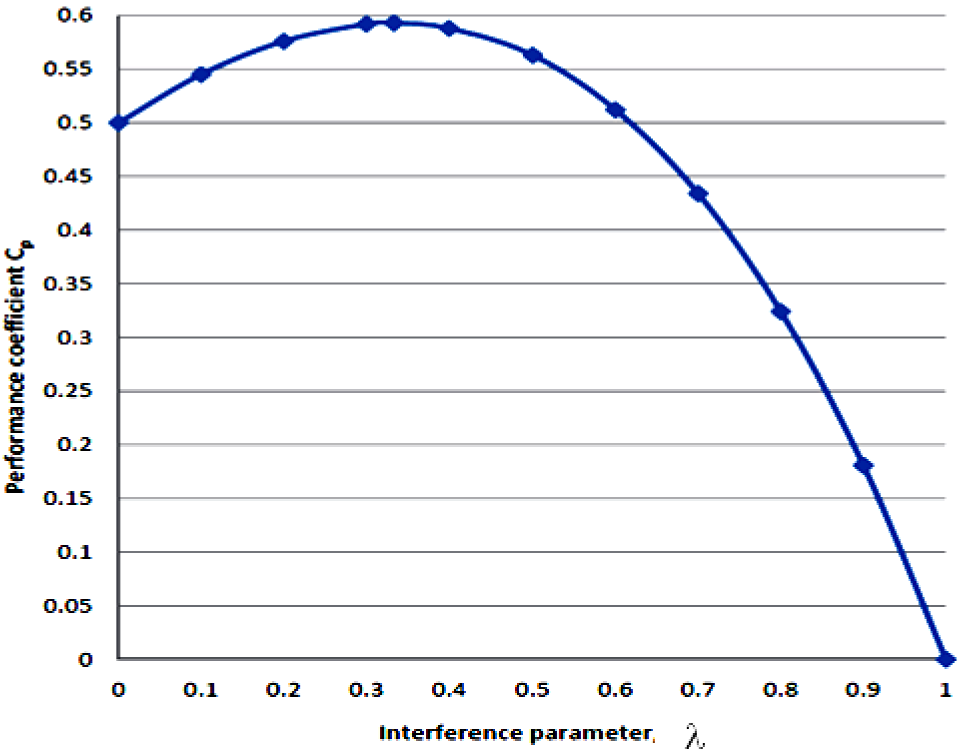


Figure 4.2 **The performance coefficient C_p as a function of the interference factor**

4.4 Rotor-Swept Area

The output power of the wind turbine varies linearly with the rotor-swept area. For the horizontal-axis turbine, the rotor-swept area is:

–

Where: D = the rotor diameter.

However, approximating the blade shape as a parabola leads to the following simple expression for the swept area:

A = 2/3 (maximum rotor width at the center) x (height of the rotor)

The wind turbine efficiently intercepts the wind energy flowing through the entire swept area even though it has only two or three thin blades with solidity between 5 - 10%.

4.5 Rotor Optimal Tip Speed Ratio, λ

The optimal tip speed ratio is an important concept relating to the power of wind turbines, which is defined as the ratio of the speed of the rotor tip to the free stream wind speed. If a rotor rotates too slowly, it allows too much wind to pass through undisturbed, and thus does not extract as much as energy as it could, within the limits of the Betz Criterion.

On the other hand, if the rotor rotates too quickly, it appears to the wind as a large flat disc, which creates a large amount of drag. The rotor Tip Speed Ratioλ depends on the blade airfoil profile used, the number of blades, and the type of wind turbine. In general, three bladed wind turbines operate at a, λ of between 6 and 8, with 7 being the most widely reported value.

In general, a high λ is desirable, since it results in a high shaft rotational speed that allows for efficient operation of an electrical generator. Disadvantages however of a high λ include:

a. Blade tips operating at 80 m/s of greater are subject to leading edge erosion from dust and sand particles, and would require special leading edge treatments like helicopter blades to mitigate such damage,
b. Noise, both audible and inaudible, is generated,
c. Vibration, especially in 2 or 1 blade rotors,
d. Reduced rotor efficiency due to drag and tip losses,
e. Higher speed rotors require much larger braking systems to prevent the rotor from reaching a runaway condition that can cause disintegration of the turbine rotor blades.

where:

V= Wind speed [m/sec]

v= ωr =Rotor tip speed [m/s]

ω= 2πf = Angular velocity [rad/sec]

f= Rotor frequency [Hz], [sec^{-1}]

r= Rotor radius [m]

t= Time [s]

Chapter Five

5. Results and Discussion

The mathematical model of the system consists of different parameters to create an initial population. These parameters consist of strings; consider a system whose mathematical models are the following:

Model

Tip speed ratio (λ),

$$\lambda = (2\pi R)\backslash(Vt)$$

Rotor radius, R = 38.5 m

A 38.5 m radius wind turbine was optimized using the described scheme at a design point of a variable wind speed.

Power coefficient, (C_p)

$$C_p = 1/2(1+\lambda)(1-\lambda^2)$$

Power output

$$P = 1/2\rho AV^3C_p$$

Air Density, $\rho = 0.97$ kg/m^3

- The air density and Wind turbine rotor radius data taken from Adama wind farm.

Cp_1 and P_1 are normal condition input and output of the system respectively

$$\lambda_n(i) = (2\pi R)\backslash V(a,b)t)$$

with variable interval, n=[1,7] and Matrix Interval (a,b)

$$C_{pn}(i) = 1/2(1+\lambda(n))(1-\lambda^2(n))$$

According to the above mathematical models, assume all the Seven States conditions for the model are very well known, those are total reference for this system.
where:

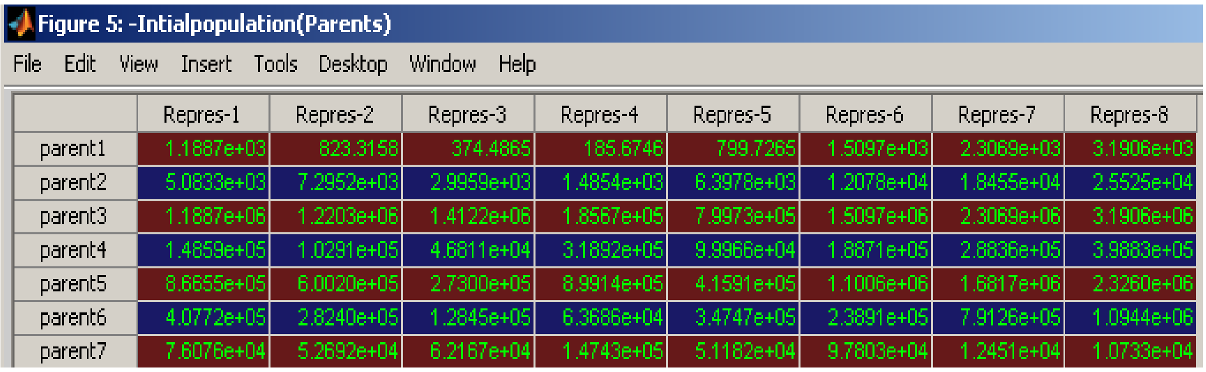
- Wind speed, V_1 Normal condition input and Power output P_1 is Normal condition output for the system.
- V_2-V_7 is the result of normal input affected by some predictable wind disturbance.
- t= time control 0.5 to 100 the total samples are 200
- V_1- V_7 input of the system with different state condition (predictable + normal input wind speed with a system)
- Power Coefficient, C_{pchild} = input with state condition (unpredictable input wind speed, $C_{pchild}=Cp_1$ with unexpected disturbance)
- $P_n=P_2$; P_3; P_4; P_5; P_6; P_7 those are output with different state condition(predictable power output),assume known very well (total reference)
- P_{child} = an output with state condition (unpredictable Power output)

There are a number of states to indicate the working condition of the rotor blade with different Power output (P's). It depends on the random predictable signal disturbances. Even if we have already understood that the power output signal is predictable, disturbances may occur sometimes but the rotor blade will function in the bounded area. So we shall approximate and select unpredictable power output from the previous predictable state condition.

5.1 Initialization of the Population

Figure 5.1, Figure 5.2 and Figure 5.3 is a characteristics graph which the data cannot simply read separate from one state to the other. Therefore, we should have to switch the data as a simple form and can be readable by using statistical representation. The methods discussed here include tables, and graphs. The proper representation depends upon the nature of the data. It deals with all aspects such as collection data, analysis and interpretation of such representative data, e.g. mean median, mode, range, variance, standard deviation and etc. Based on standard deviation representation, Table 5.1 is the initial population of the model.

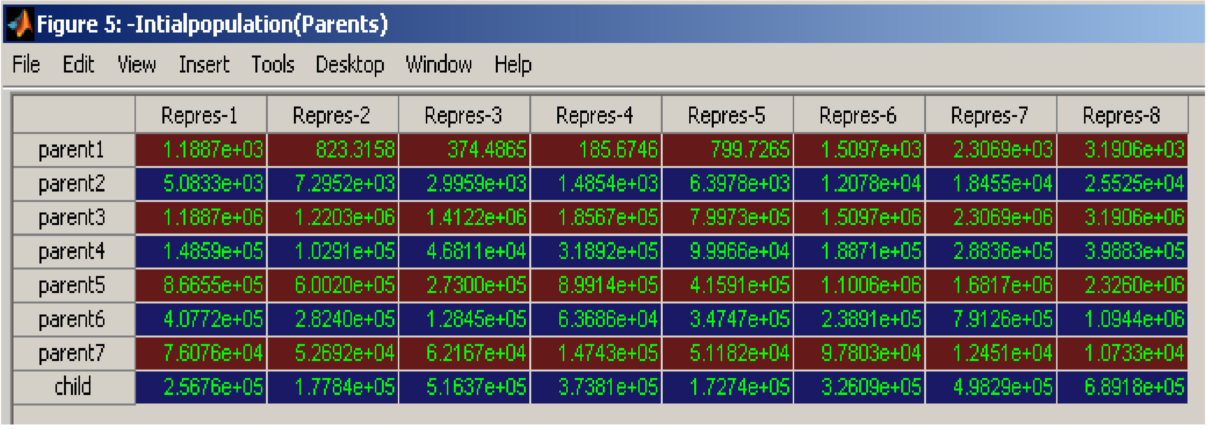
Table 5.1 The initial population of one of those models



	Repres-1	Repres-2	Repres-3	Repres-4	Repres-5	Repres-6	Repres-7	Repres-8
parent1	1.1887e+03	823.3158	374.4865	185.6746	799.7265	1.5097e+03	2.3069e+03	3.1906e+03
parent2	5.0833e+03	7.2952e+03	2.9959e+03	1.4854e+03	6.3978e+03	1.2078e+04	1.8455e+04	2.5525e+04
parent3	1.1887e+06	1.2203e+06	1.4122e+06	1.8567e+05	7.9973e+05	1.5097e+06	2.3069e+06	3.1906e+06
parent4	1.4859e+05	1.0291e+05	4.6811e+04	3.1892e+05	9.9966e+04	1.8871e+05	2.8836e+05	3.9883e+05
parent5	8.6655e+05	6.0020e+05	2.7300e+05	8.9914e+05	4.1591e+05	1.1006e+06	1.6817e+06	2.3260e+06
parent6	4.0772e+05	2.8240e+05	1.2845e+05	6.3686e+04	3.4747e+05	2.3891e+05	7.9126e+05	1.0944e+06
parent7	7.6076e+04	5.2692e+04	6.2167e+04	1.4743e+05	5.1182e+04	9.7803e+04	1.2451e+04	1.0733e+04

5.2 Encoding

Table 5.2 Encode initial population



	Repres-1	Repres-2	Repres-3	Repres-4	Repres-5	Repres-6	Repres-7	Repres-8
parent1	1.1887e+03	823.3158	374.4865	185.6746	799.7265	1.5097e+03	2.3069e+03	3.1906e+03
parent2	5.0833e+03	7.2952e+03	2.9959e+03	1.4854e+03	6.3978e+03	1.2078e+04	1.8455e+04	2.5525e+04
parent3	1.1887e+06	1.2203e+06	1.4122e+06	1.8567e+05	7.9973e+05	1.5097e+06	2.3069e+06	3.1906e+06
parent4	1.4859e+05	1.0291e+05	4.6811e+04	3.1892e+05	9.9966e+04	1.8871e+05	2.8836e+05	3.9883e+05
parent5	8.6655e+05	6.0020e+05	2.7300e+05	8.9914e+05	4.1591e+05	1.1006e+06	1.6817e+06	2.3260e+06
parent6	4.0772e+05	2.8240e+05	1.2845e+05	6.3686e+04	3.4747e+05	2.3891e+05	7.9126e+05	1.0944e+06
parent7	7.6076e+04	5.2692e+04	6.2167e+04	1.4743e+05	5.1182e+04	9.7803e+04	1.2451e+04	1.0733e+04
child	2.5676e+05	1.7784e+05	5.1637e+05	3.7381e+05	1.7274e+05	3.2609e+05	4.9829e+05	6.8918e+05

child	2.5676e+05	1.7784e+05	5.1637e+05	3.7381e+05	1.7274e+05	3.2609e+05	4.9829e+05	6.8918e+05

5.3 Evaluation of the Fitness Function and Selection

1st Step - how the “fitness’ of solutions is to be calculated. The situation for a function optimization problem is straight forward using the following Equations:

5.4 Reproduction

Before achieving of final output or rejection of the iteration, a number of offspring generate. In each iteration, can find out variable offspring’s which the proposition of reproduction with Single iteration.

5.4.1 Simple Crossover

Offspring from all parents:

4.0772	1.6470	0.7492	2.3105	1.8517	2.0599	4.6149	6.4852
1.4859	1.4343	0.6524	2.6130	1.5584	2.0004	4.0189	6.2096

5.4.2 Linear crossover

0.4077	0.2824	0.1284	0.1276	0.3475	0.2389	0.7913	1.0944
0.1486	0.1029	0.0468	0.2550	0.1000	0.1887	0.2884	0.3988

5.4.3 Boundary Mutation

If $R_{nd} \le P_{bm}$ then (mutate X_j (t+1)) , else no change to the gene
Random Probability, $R_{nd} = 0.7431$ and Probability Boundary Mutation, $p_{bm} = 0.5000$

0.4077	0.2824	0.1284	0.1276	0.3475	0.2389	0.7913	1.0944
0.1486	0.1029	0.0468	0.2550	0.1000	0.1887	0.2884	0.3988

Over all GAs is based on correlation with the genetic configuration and behavior of chromosomes within a population of individuals using different fundamentals such as

- Compete for resources and mates.
- Most successful in each 'competition' will create more offspring than that perform poorly.
- Genes from `good' individuals spread throughout the population in order that two good parents will sometimes produce offspring that are better than either parent.
- Each successive generation will become more suited to their environment.

5.5 Performance Evaluation of the Genetic Algorithm

Wind turbines are subjected to environmental conditions which may affect their loading, durability and operation. To ensure an appropriate level of safety and reliability, the environmental parameters shall be taken into account during the selection of appropriate wind turbines.
A 38.5 m radius wind turbine was optimized using the described scheme at a design point of a variable wind speed. The rotor providing the basis for the population was created by using the GOLDWIND GW77/1500 is designed in accordance with IEC II-A type of wind turbine airfoils as the root, middle, and tip airfoils, respectively.

Performance is measured by phenotype value based on comparison of individual representative data and graph for the given model and genotype value to converge the solution based on number of iteration, elapsed time and the least difference between child such as unpredictable condition and the best fittest state. Each generation consists of a population of character strings that are analogous to the chromosome. Each individual represents a point in a search space and a possible solution. The individuals in the population are then made to go through a process of evolution.

In each of the experiments throughout the simulation, several random generators are considered with each operation being done for 200 times.

The simulation outcome is shown below in Figure 5.1, Figure 5.2, Figure 5.3, Figure 5.4 the phenotype result of model system output for the varying power output versus time of each parent. To read the values for all outputs of the initial population Figure 5.4 indicated properly.

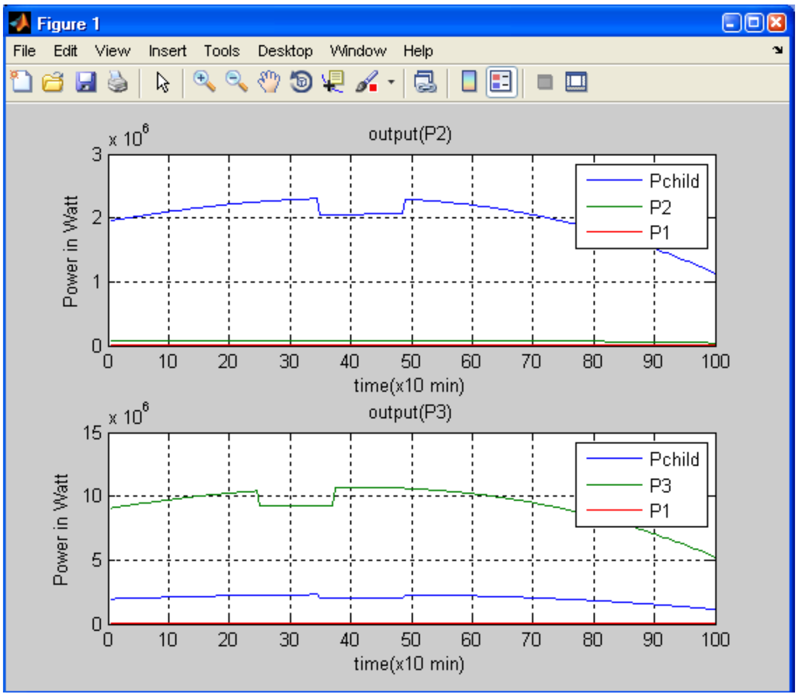


Figure 5.1 Output of initial population

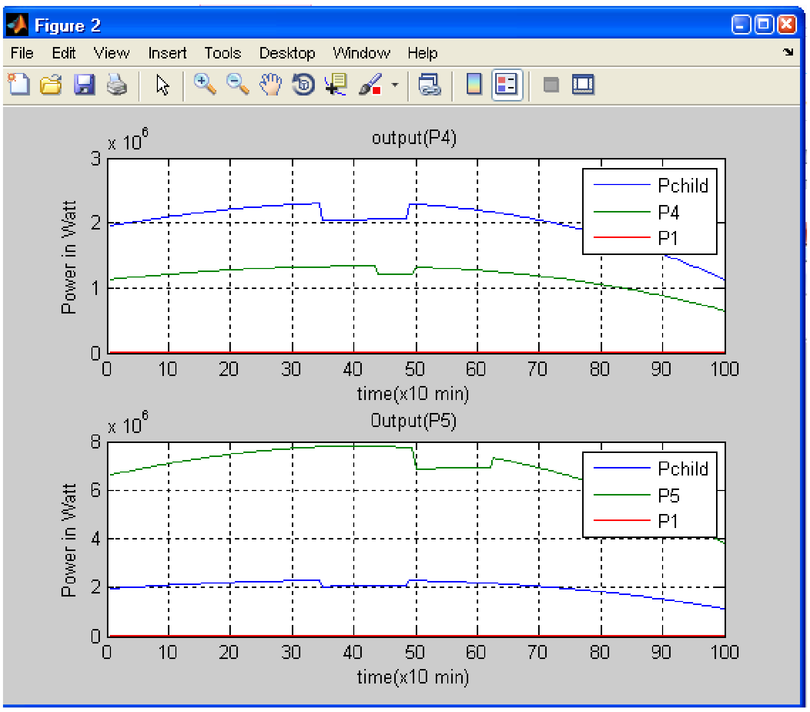


Figure 5.2 Output of initial population

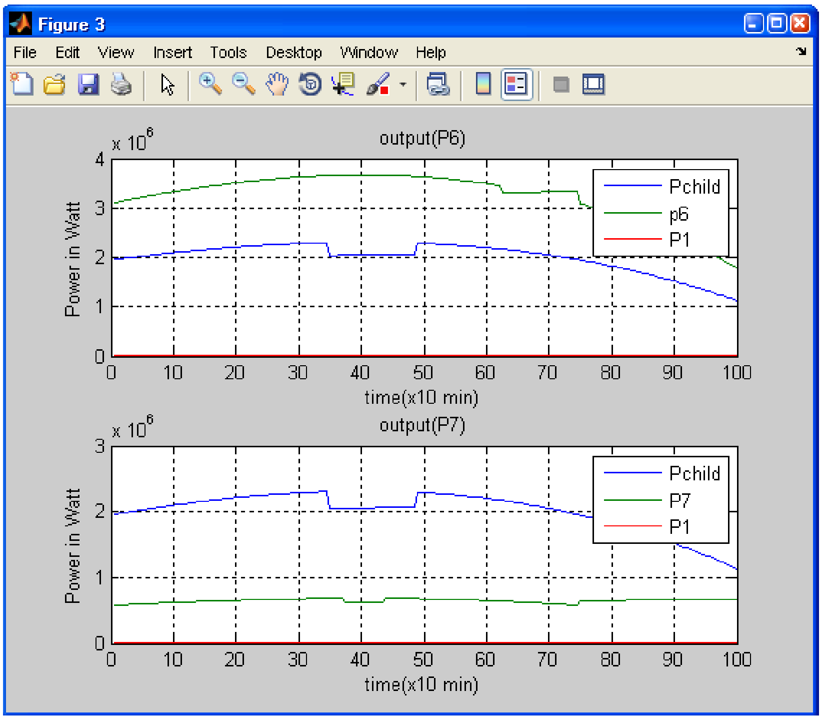
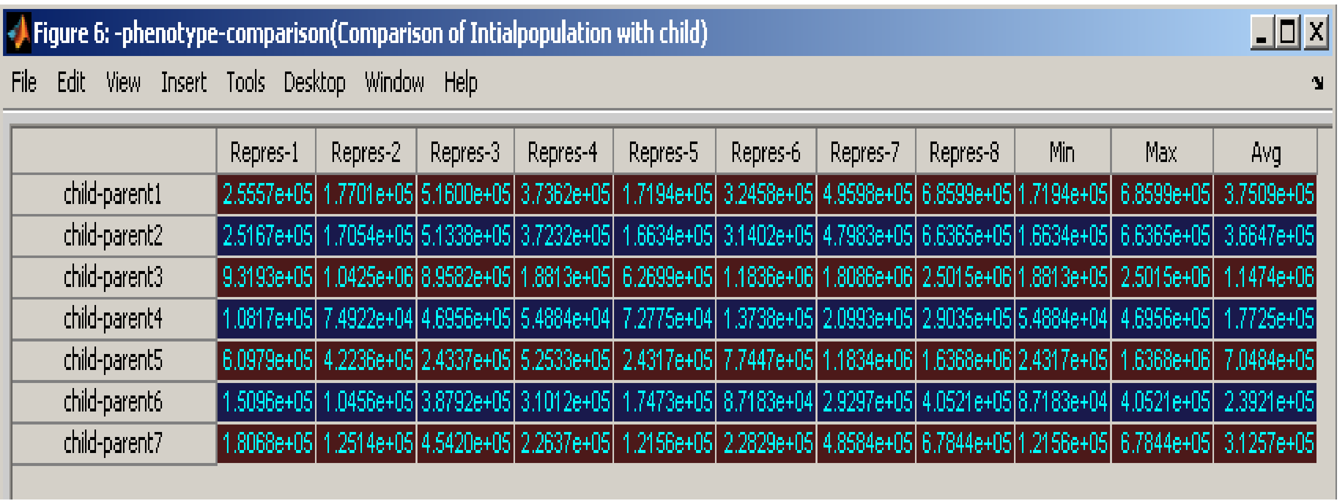


Figure 5.3 Output of initial population

Table 5.3. Phenotype comparison between parents and child



	Repres-1	Repres-2	Repres-3	Repres-4	Repres-5	Repres-6	Repres-7	Repres-8	Min	Max	Avg
child-parent1	2.5557e+05	1.7701e+05	5.1600e+05	3.7362e+05	1.7194e+05	3.2458e+05	4.9598e+05	6.8599e+05	1.7194e+05	6.8599e+05	3.7509e+05
child-parent2	2.5167e+05	1.7054e+05	5.1338e+05	3.7232e+05	1.6634e+05	3.1402e+05	4.7983e+05	6.6365e+05	1.6634e+05	6.6365e+05	3.6647e+05
child-parent3	9.3193e+05	1.0425e+06	8.9582e+05	1.8813e+05	6.2699e+05	1.1836e+06	1.8086e+06	2.5015e+06	1.8813e+05	2.5015e+06	1.1474e+06
child-parent4	1.0817e+05	7.4922e+04	4.6956e+05	5.4884e+04	7.2775e+04	1.3738e+05	2.0993e+05	2.9035e+05	5.4884e+04	4.6956e+05	1.7725e+05
child-parent5	6.0979e+05	4.2236e+05	2.4337e+05	5.2533e+05	2.4317e+05	7.7447e+05	1.1834e+06	1.6368e+06	2.4317e+05	1.6368e+06	7.0484e+05
child-parent6	1.5096e+05	1.0456e+05	3.8792e+05	3.1012e+05	1.7473e+05	8.7183e+04	2.9297e+05	4.0521e+05	8.7183e+04	4.0521e+05	2.3921e+05
child-parent7	1.8068e+05	1.2514e+05	4.5420e+05	2.2637e+05	1.2156e+05	2.2829e+05	4.8584e+05	6.7844e+05	1.2156e+05	6.7844e+05	3.1257e+05

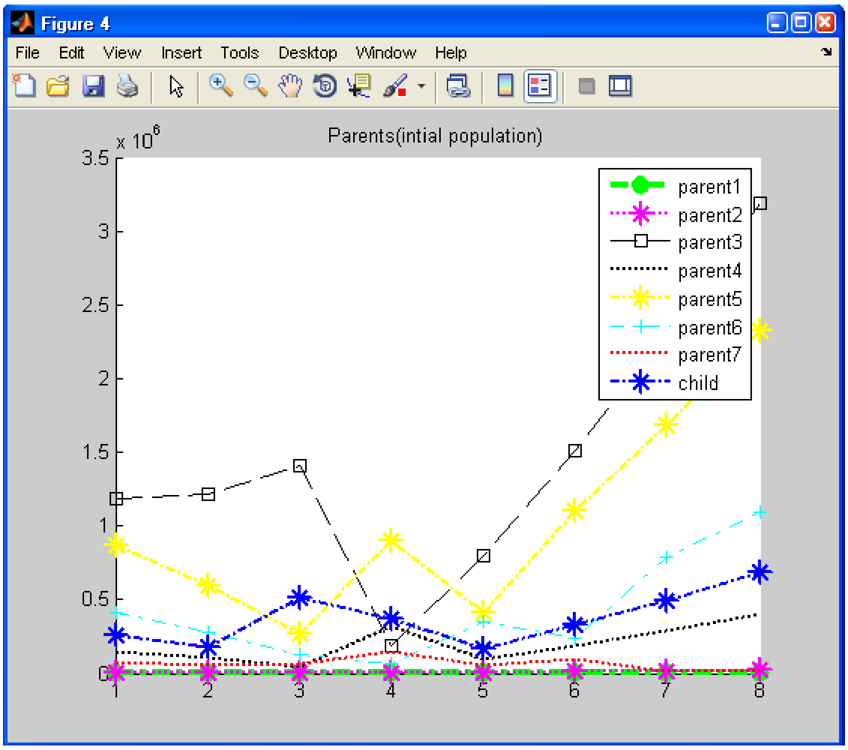
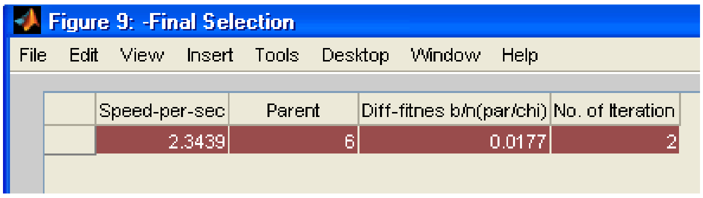


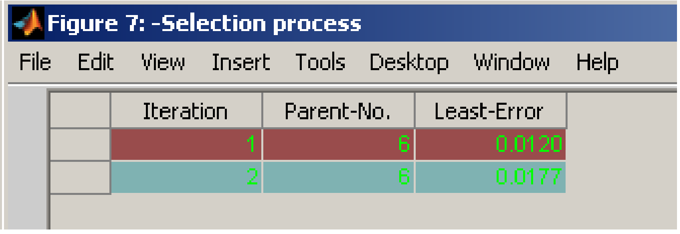
Figure 5.4 Phenotype comparison value of all output of initial population

Table 5.4 Final Genotype Selection



Speed-per-sec	Parent	Diff-fitnes b/n(par/chi)	No. of Iteration
2.3439	6	0.0177	2

Table 5.5 Least Error Selection Process



Iteration	Parent-No.	Least-Error
1	6	0.0120
2	6	0.0177

The phenotype result of Figure 5.4, Table 5.3 and genotype result of Table 5.4 indicate state based on unpredictable fault is approximately similar to parent 7 and genotype result of Table 5.5 with different Genetic Algorithm operators has taken variable wind speed of iteration, error and elapsed time to the same state for Linear crossover and Heuristic crossover with different mutation such as uniform and boundary.

Chapter Six

6. Conclusion and Recommendation

6.1 Conclusion

The major purpose of this thesis is to design a Genetic Algorithm based Approximation of Wind Turbine System State, subjected to bounded Wind Speed Disturbances mechanism for the systems where power disturbances are assumed to be random signals, whose values are in a known limited intervals.

To work this thesis is studying a mathematical model of non-linear systems such as model to analyze different possible disturbances by wind speed on the wind turbine power output with one interval for each parent in a given time. There are numerous mathematical models tried and obtained the above model for better results.

A new approach Genetic Algorithm (GA) has been used for the prediction of wind energy in this paper. In this study, variable wind speed and time are taken as inputs and wind energy (power) generated is considered as output. The GA method showed better performance in terms of the mean square error and is preferred for prediction of wind energy in real time environment within a given period of time.

In chapter five from the simulation result analysis, based on genotype result using the performance measurement metrics (i.e. number of iteration, error and elapsed time) it can be clearly observed that linear crossover has similar result with heuristic crossover as well as simple crossover to converge the approximation state.

Genetic algorithm is a promising approach for modeling the power systems that inspired their design. Most models using GAs are meant to be "idea models “rather than precise simulations attempting to match real world data. This paper presented how to approximate a wind turbine state subjected to bounded wind speed disturbances based on evolutionary strategy and proposes a genetic algorithm approach to find out solutions of the problem with any mathematical equations.

6.2 Recommendation

Recommendations for future work on this thesis have been made such as:

- The aerodynamic performance and noise generation of the blade as well as the power output of the wind turbine should be performed using Genetic algorithm.
- Rotors should be optimized at a constant wind speed operating points which vary in time by comparing XFOIL code and Genetic algorithm code.
- Experimental testing should be carried out for the most effective blade design and configurations.
- A detailed airfoil shape model of a turbine component such as different number rotor blade should be developed and implemented.

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