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MODELING OF WIND ENERGY HARVESTING SYSTEM: A SYSTEMATIC REVIEW

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Abstract

Energy consumption increases gradually due to the rapid advancement in the industrial sectors; increase in population and also due to fast growing of urbanization. The conventional energy sources which include power plants using fossil fuels are widely used as a source of energy all over the world so far. As these conventional energy sources used nowadays are coming to an end in a near future, the sustainability of power supplies is one of the most challenging issues that the world faces today. To overcome the increasing power demand and depletion of conventional energy sources around the world, the use of clean, non-polluting and renewable energy is very important. Global warming and environmental pollution are major challenges to the earth's safety and security. Wind energy has become a best alternative of traditional fossil fuel power plants with the successful operation of multi-megawatt sized wind turbines. The fluctuating and unpredictable nature of wind is the major problem in harnessing wind energy. So, it is very important to improve the operation of wind turbine for its safety and better efficiency of wind energy harvesting system. Several methods have been used to improve the quality and efficiency of wind power system. An Adaptive Neuro-Fuzzy Inference System (ANFIS) model was used by many researchers to control factors affecting wind and predict the power output from wind to increase the efficiency of the WEHS. This review paper focuses on wind energy systems to develop a model to produce optimal energy components for a typical rural community for minimizing the total net present cost of the system through the life time of the project.

Keywords: Renewable Energy, Wind Energy Harvesting System (WEHS), Wind turbines.

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1. Introduction

Energy is one of the major components for the social and economic development of any country. There is a close relation between the availability of energy and the future growth of a nation. In developing countries, the energy sector assumes a critical importance in view of the ever-increasing energy needs requiring huge investments to meet them. Energy consumption increases gradually due to the rapid advancement in the industrial sectors; increase in population and also due to fast growing of urbanization. Energy can be consumed in a variety of forms. Fuel wood, animal waste (cow dung) and agricultural residues are traditional sources of energy that continue to meet the bulk of energy requirement in rural (remote) areas. These non-commercial fuels are gradually getting replaced by commercial fuels such as coal, lignite, refined petroleum products, natural gas and electricity. In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population.
Energy can be classified as primary and secondary energy sources. Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass (such as wood). Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity. Primary energy sources are costly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity. Moreover, energy can also be classified into renewable and non-renewable sources of energy. Renewable sources of energy are those natural resources which are inexhaustible and can be used to produce energy again and again. The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants. Examples are solar energy, wind energy, geothermal energy, tidal energy, water energy (hydro electric power) and biomass energy. Non-Renewable sources of energy are those natural resources which are exhaustible and once they are used cannot be replaced which are likely to deplete with time. Examples are fossil fuels such as coal, oil and natural gas etc. which together supply 98% of the total world energy demand today. These conventional energy sources which include power plants using fossil fuels are widely used as a source of energy all over the world so far. As the conventional energy sources used nowadays are coming to an end in a near future, the sustainability of power supplies is one of the most challenging issues that the world faces today. Energy wars may already be observed in many parts of the world [1]. To overcome the increasing power demand and depletion of conventional energy sources around the world, the use of clean, non-polluting and renewable energy is very important. Global warming and environmental pollution are major challenges to the earth's safety and security. The rising concerns over global warming, environmental pollution, and energy security have increased interest in developing renewable and environmentally friendly energy sources such as wind, solar, hydropower, geothermal, hydrogen and biomass as the replacements for fossil fuels.

The energy requirement of remote areas can be met by locally available renewable energy sources like wind as it is difficult to service these areas through the conventional power grid. Since remote areas are inaccessible areas with consequent implication for maintenance, the developed control systems should be reliable and needs to be fault-tolerant control. Moreover wind energy systems exhibit nonlinear behavior and are required to operate over a wide range of excitations. Energy production is not the only criterion to be considered when installing new wind turbines; cost efficiency, the impact on the environment and electric grid are some of important issues of significant interest when making decisions about new wind turbine installations. Recent technological developments have improved the cost effectiveness of many of the Wind Energy harvesting System (WEHS). The WEHSs have particular physical constraints like

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displacements, velocities, accelerations, forces, wind speed, air density, temperature and pressure which must be strictly observed if such systems are to operate effectively and have economically attractive and useful operational lifetimes.

1.1 Wind Energy

Among renewable power sources, wind as an energy resource has gained significant focus around the world. Wind energy has become a best alternative of traditional fossil fuel power plants with the successful operation of multi-megawatt sized wind turbines. The power of wind is generally regarded as one of the very important sources that plays a leading role due to availability of high wind pressure, clean, pollution free, and provides inexhaustible sustainable energy all over the world. It can provide suitable solutions to the global climate change and energy crisis. The utilization of wind power essentially reduces emissions of CO_2, SO_2, NO_x and other harmful wastes as in traditional coal-fuel power plants or radioactive wastes in nuclear power plants. Moreover, it is believed that wind energy will be one of the most cost effective sources of electrical power in the near future. During the recent decades, tremendous growth in wind power has been seen all over the world. The global market for wind power has been expanding faster than any other sources of renewable energy. According to the Global Wind Energy Council (GWEC) report, in a year 2016 the global annual installed wind generation capacity reached approximately 486.7 GW which is an increase of 12.5% compared to the previous year. Five year forecast of GWEC's sees almost 60 GW of new wind installations in 2017, rising to an annual market of about 75 GW by 2021, to bring cumulative installed capacity of over 800 GW by the end of 2021 [2]. As wind power is the most promising energy sources, it is highly expected to take a much higher portion in power generation in the coming decades. However, this absolutely free source of energy is not abundantly available everywhere to build an economical wind energy harvesting system. The air density and wind profile of the site must be properly investigated before installation. The increased height of turbine rotor leads to more generated power because wind speed increases with height. In order to assess the potential of a WEHS, it is imperative to have precise knowledge of wind speed profiles [3].

1.1.1 Advantages of wind energy

Wind energy has numerous different benefits in helping to provide a source of clean and renewable electricity power for countries all over the world. The advantages of wind energy are more apparent than the disadvantages. Some advantages of wind energy are:

a) Environmentally Friendly sources of energy

Fossil fuels emit high levels of greenhouse gas such as carbon dioxide (CO_2) or methane (CH_4), which are greatly responsible for global warming, climate change, and degradation of air quality. Also it emits sulfur to the atmosphere leading to acid rains. Acid rains can cause damage to buildings. Unlike fossil fuels wind energy provides clean energy which is non-pollutant and non-contributor to greenhouse effects and global warming. It should be noted that noise and visual pollution are both environmental factors, but they don't have a negative effect on the earth, water table or the quality of the air we breathe. Therefore, solar and wind power are considered as eco-friendly sources of energy because they emit zero toxic gases to the environment.

b) Wind Energy is Free

Sources of energy like fossil fuels (oil, coal, and natural gas) are limited sources of energy and there is strong possibility that they will run out in the near future. These sources of energy have tendency to trade disputes, political instabilities, spike in energy prices and unnecessary wars. These variables affect a lot more than a nation's energy policies; they can significantly drain a county's economy. Unlike fossil fuel, wind energy is completely free and available everywhere. There's no market for the supply and demand of wind energy and it can be used by anyone and will never run out. Wind energy doesn't deplete over a lifetime and there is zero possibility that they will run out (sustainable source of energy). Harvesting the kinetic energy of wind doesn't affect currents or wind cycles in any way. This can help to conserve dwindling supplies of the earth's natural resources, allowing them to last longer and help to support future generations. This makes wind energy a viable option for generating cheap electricity.

c) Industrial & Domestic Installations

Wind turbines aren't just limited to industrial-scale installations such as wind farms. They can also be installed on a domestic scale, with many landowners opting to install smaller, less powerful wind turbines in order to provide part of a domestic electricity supply. Domestic wind turbines are often coupled with other renewable energy technologies such as solar panels or geothermal heating systems. Wind turbines can play a key role in helping to bring power to remote locations. This can help to benefit everything from a small off-grid village to a remote research station.

d) Wind Technology Becoming Cheaper, low maintenance and running cost

Wind turbines have improved significantly after the first electricity-generating wind turbine was invented in1888 and nowadays the technology is beginning to come down in price, making it much more accessible. Government subsidies are also helping to reduce the cost of a wind turbine installation, with many governments across the world providing incentives for not only the installation of such technologies, but also for the ongoing supply of environmentally friendly electricity. A new wind turbine can be expected to last some time prior to any maintenance work needing to be carried out and relatively have low maintenance cost.

e) Job Creation and Increases Energy Security

War, politics and overall demand often dictate the price for non-renewable energy resources, which can fluctuate and cause serious economic problems or supply shortages for some countries. By using renewable energy sources a country can help to reduce its dependency on global markets and thus increase its energy security. Since wind turbines first became available on the market the wind energy industry has boomed. This has helped to create jobs all over the world. Wind energy development creates thousands of long-term, high-paying jobs in fields such as wind turbine component manufacturing, construction and installation, maintenance and operations, legal and marketing services, transportation and logistical services, wind energy consulting where specialist consultants will determine whether or not a wind turbine installation will provide a return on investment and more.

1.1.2 Disadvantages of wind energy

a) The Wind Fluctuates

Although wind energy is sustainable and will never run out, the wind isn't always blowing and abundantly available everywhere. This can cause serious problems for wind turbine developers who will often spend significant time and money investigating whether or not a particular site is suitable for the generation of wind power. For a wind turbine to be efficient, the location where it is built needs to have an adequate supply of wind energy. This is why we often see wind turbines built on top of hills or out at sea, where there are less land obstacles to reduce the intensity of wind energy.

b) Installation is Expensive

Although costs are reducing over time, constructing turbines and wind facilities is considered expensive. First, a site survey will need to be carried out which may involve having to erect a sample turbine to measure wind speeds over a significant period of time. If deemed adequate, the wind turbine will need to be manufactured, transported and erected on top of a pre-built foundation. All of these processes contribute to the overall cost of installing a wind turbine. When the above processes are taken into account for offshore wind farms, costs become much greater. It's much harder to install wind turbines out at sea than it is on land, and some companies have even commissioned bespoke ships capable of transporting and installing wind turbines at sea.

c) Noise and Visual Pollution

One of the most popular disadvantages of wind turbines is the noise pollution that they generate. A single wind turbine can be heard from hundreds of meters away. Combine multiple wind turbines and the audible effects can be much greater. Noise pollution from wind turbines has ruined the lives of some homeowners. Although steps are often taken to site wind turbines away from dwellings, they do sometimes get built too close to where people live and this is why new wind farms often come up against strong public objection. Another widely reported disadvantage of wind turbines is visual pollution. Although many people actually like the look of wind turbines, others do not and see them as a blot on the landscape. This tends to come down to personal opinion, and as more wind farms are built, public acceptance is becoming common place.

d) Threat to Wildlife

Wind turbines may be dangerous to flying animals. It's widely reported that wind turbines pose a threat to wildlife, primarily birds and bats. Many birds and bats have been killed by flying into the rotors. Nevertheless, wind turbines are contributing to mortality rates among bird and bat populations. Experts are now conducting research to learn more about the effects that wind turbines have on marine habitats.

e) Remoteness of location

Although this may be an advantage (placing wind turbines in desolate areas, far away from people), it may also be a disadvantage. The cost of travel and maintenance on the turbines increases and is time consuming. Offshore wind turbines require boats and can be dangerous to manage. In the darkness/at night it may be difficult for incoming boats to see wind turbines installed on offshore thus leading to collisions

1.2. Wind Energy Harvesting System

The major components of a typical WEHS are wind turbine, gear box, a generator, control system and interconnection devices [4].

a) Wind turbines

The most important part of a wind energy harvesting system is the wind turbine, which transforms the kinetic energy of wind into mechanical energy. The mechanical energy can be used to drive the generator to generate electricity. The wind turbine is basically composed of a blade, a mechanical part and an electric engine coupled to each other. The power generated by any wind turbine depends on parameters such as turbine type, the number of blades and the power factor [5]. Wind turbines are classified, in the basis of their axis in which the turbine rotates, into horizontal axis and vertical axis wind turbines.

Because of the ability of the horizontal axis turbines to collect the maximum amount of wind energy for the time of day and season and to adjust their blades to avoid high wind storms they are considered more common than vertical-axis turbines. The kinematical energy of wind is the function of wind speed, the specific mass of air, the area of air space where the wind is captured and the height at which the rotor is placed. The power available in a uniform wind field can as expressed as

$$P_w = \frac{1}{2} A\rho v^3 \tag{1}$$

Where A is the rotor swept area (m^2), v is the wind speed (m/s) and ρ is the density (kg/m^3). Wind turbine can extract only a portion of available wind power. The mechanical power generated by a wind turbine is proportional to the rotor swept area, wind speed, rotor speed and power coefficient (rated power) denoted by C_P. Power coefficient is a measure of the efficiency of wind turbine and a nonlinear function of operating tip-speed ratio (TSR) and pitch angle. It describes how efficiently a wind turbine converts wind energy into mechanical energy. C_P is calculated as the ratio of mechanical power delivered (P_m) by the system to the total power available on the cross sectional area of the wind stream (P_w) subtended by the wind turbine according to the following relationship.

$$C_P = \frac{P_m}{P_w} \tag{2}$$

$$P_m = C_P.\frac{1}{2}\rho A v^3 \tag{3}$$

The accurate estimation of power coefficient is very important to design different control strategies for WECS, especially maximum power controller. For any wind turbine the value of C_P can never exceed 0.593. Every wind turbine has different relationship of power coefficient with operating TSR which is difficult to determine in practice. The relationship of power coefficient is provided by the wind turbine manufacturer documentation, which is used to design any control scheme. The tip-speed ratio (λ) is defined as the ratio of the tangential velocity of the blade tips (machine's rotational speed) divided by the effective wind speed. The value of TSR changes with wind speed and rotor speed.

$$\lambda = \frac{\omega_r R}{v} \tag{4}$$

Therefore, the value of C_P changes with λ, so C_P is a function of wind speed v, rotor speed ω_r (rad/s), rotor radius R(m) and collective blade pitch angle β(°). At different blade angle, the power coefficients vary with tip speed ratio. Where the β gradually increases, the curve of Cp will decrease significantly. Generally, to achieve the maximum wind power, β value should be very small. If β is at a given value, then Cp has a maximum value Cpmax.
Generally it can be expressed as

$$C_P = (\lambda, \beta) \tag{5}$$

Power coefficient reaches to its maximum value for optimal value of TSR and this is called the optimal operating point of wind turbine. So, it is very important to accurately estimate the wind turbine power coefficient during operation. The optimum value of TSR depends on shape of blade and number of blades. In order to extract maximum power, wind turbine is operated at optimal value of TSR, having the maximum value of power coefficient ($C_{P\max}$). During operation of wind turbine, TSR can be controlled by adjusting the rotor speed and this control should be based on real time information of wind speed. When wind speed is below the rated speed, the optimal value of TSR is achieved by rotor torque/speed control while operating the variable speed wind turbine at a constant pitch angle.

b) Wind Turbine Generators

One of the factors affecting wind turbines lies in their generator technology. There is no common agreement among industry on the best wind turbine generator technology. There are different wind energy harvesting systems configurations depending on using synchronous (induction) or asynchronous machines and stall-regulated or pitch regulated systems. The functional objective of these systems is the same. i.e., converting the wind kinetic energy into electric power and injecting this electric power into a utility grid. A problem is on the size of wind turbine and choosing the optimal configuration of the turbine's parts [6]. Traditionally, there are three main types of wind turbine generators (WTGs) which can be considered for the various wind turbine systems, these are direct current (DC), alternating current (AC) synchronous and AC asynchronous generators. In principle, each can be run at fixed or variable speed. Due to the fluctuating nature of wind power, it is advantageous to operate the WTG at variable speed which reduces the physical stress on the turbine blades and drive train, and which improves system aerodynamic efficiency and torque transient behaviors. Modern wind turbine systems use three phase AC generators. The common types of AC generator that are possible candidates in modern wind turbine systems are Squirrel cage induction generator (SCIG), Wound rotor induction generator (WRIG), Doubly-Fed Induction Generator (DFIG), Wound rotor synchronous generator (WRSG) and Permanent magnet synchronous generator (PMSG).

c) Gearbox

The gearbox in the mechanical connection converts slower rotational speeds of the wind turbine to higher rotational speeds on the electric generator. The connection between an electrical generator and the turbine rotor may be direct or through a gearbox. The gearbox helps the matching of the generator speed to that of the turbine irrespective of varying wind speeds. The use of gearbox is dependent on the kind of electrical generator used in WEHS. However, disadvantages of using a gearbox are reductions in the efficiency and, in some cases, reliability of the system.

d) Power electronic converter

The Power electronic (PE) converter has an important role in modern WEHS with variable-speed control method. It is an essential part for integrating the variable-speed wind power generation units to achieve high efficiency and performance in power systems [7]. The constant-speed systems hardly include a PE converter, except for compensation of reactive power. Due to rapid developments in power electronics, semiconductor devices are gaining higher current and voltage ratings, less power losses, higher reliability, as well as lower prices per kVA. The power passing through the PE converter (that determines the capacity of the PE converter) is dependent on the configuration of WEHS. Therefore, PE converters are becoming more attractive in improving the performance of wind turbine power generation systems.

e) Control system

A control system is a device which controls each and every operation in a decision- making system. There is growing interest in controlling wind turbines or wind plants in an intelligent manner to minimize the cost of wind energy. It brings stability to the system when there is a disturbance to safeguard the equipment from further damage. In the WEHS, the control problem consists of delivering the maximum power available from the wind to ensure the system reliability and security in order to deal with the variable nature of the generated energy. This can be done by controlling the turbines to extract efficient energy from the wind.

1.3 Factors affecting wind energy

The parameters that affect the power generated of wind turbines can be classified into two categories, namely, the site in which the turbine will be installed, and the wind turbine itself.

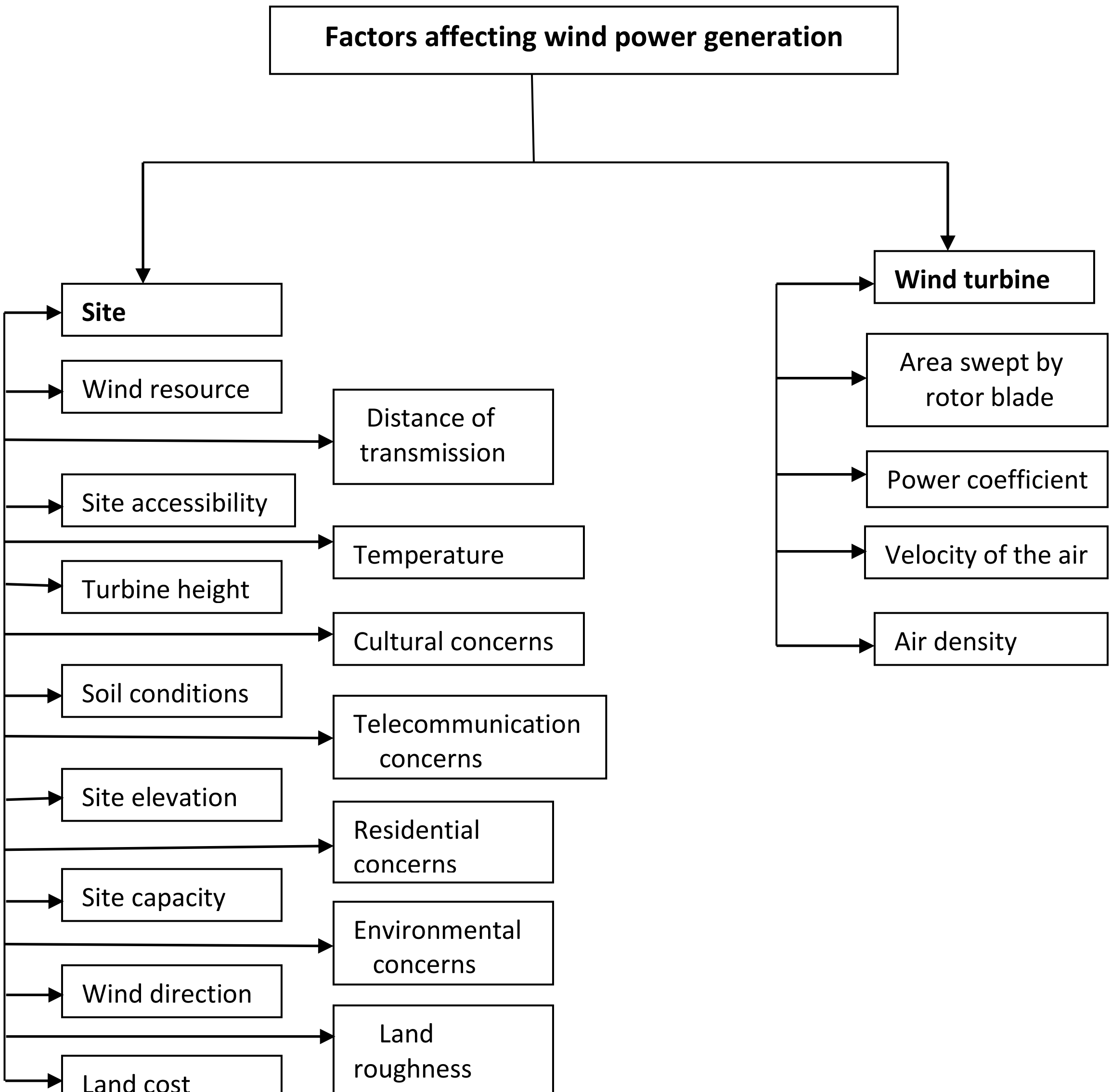

Figure1. Classification of factors that affect wind power generation [8]

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a. Blade Swept Area

The blade swept area can be calculated from the formula:

$$A = \pi[(1+r)^2 - r^2] = \pi l(l+2r) \tag{6}$$

where l is the length of wind blades and r is the radius of the hub. Thus, by doubling the length of wind blades, the swept area can be increased by the factor up to 4. When $l >> 2r$, $A \approx \pi l^2$.

b. Air density

Another important parameter that directly affects the wind power generation is the density of air. Factors like temperature, atmospheric pressure, elevation and air constituents affect the density of air.

Dry air can be considered as an ideal gas. According to the ideal gas law,

$$pV_G = nRT \tag{7}$$

where p is the pressure, V_G is the volume of the gas, n is the number of kilo moles of the gas, R is the universal gas constant (287 J/kg-K for air) and T is the temperature. Density of air, which is the ratio of the mass of 1 kilo mole of air to its volume, is given by

$$\rho = \frac{m}{V_G} \tag{8}$$

From eqn.(7) and eqn.(8) density of air is given by

$$\rho = \frac{mp}{RT} \tag{9}$$

If we know the elevation Z and temperature T at a site, then the air density can be calculated by

$$\rho = \frac{353.049}{T} e^{\left(-0.034\frac{Z}{T}\right)} \tag{10}$$

The density of air decreases with the increase in site elevation and temperature. Hence large sized systems are often required for substantial power production.

c. Wind Speed

Wind speed is one of the most critical characteristics in wind power generation. In fact, wind speed varies in both time and space, determined by many factors such as geographic and weather conditions. Because wind speed is a random parameter, measured wind speed data are usually dealt with using statistical methods. When the wind velocity is doubled, the available power increases by 8 times. In other words, for the same power, rotor area can be reduced by a factor of 8, if the system is placed at a site with double the wind velocity. The advantages are obvious. Hence, selecting the right site play a major role in the success of a wind power projects. The wind turbines depend on the same aerodynamic forces created by the wings of an aero plane to cause rotation. An anemometer that continuously measures wind speed is part of most wind turbine control systems. When the wind speed is high enough to overcome friction in the wind turbine drive train, the controls allow the rotor to rotate, thus producing a very small amount of power. This cut-in wind speed is usually a gentle breeze of about 4 m/s. Power output increases rapidly as the wind speed rises. When output reaches the maximum power the machinery was designed for, the wind turbine controls govern the output to the rated power. The wind speed at which rated power is reached is called the rated wind speed of the turbine, and is usually a strong wind of about 15 m/s. Eventually, if the wind speed increases further, the control system shuts the wind turbine down to prevent damage to the machinery. This cut-out wind speed is usually around 25 m/s.

The power generation using wind energy is possible in two ways. Constant speed operation where the generator is directly connected to the electrical grid and variable speed operation where the generator is controlled by power electronic devices. Variable-speed operation has many advantages over fixed-speed wind power generation due to so many reasons. Some of them are increased energy capture, operation at MPPT over a wide range of wind speeds, high power quality, reduced mechanical structure stresses, and

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aerodynamic noise improved system reliability and it can provide (10%–15%) higher output power and has less mechanical stresses when compared with the operation at a fixed speed [9,10].

1.4 Need of modeling wind energy

The energy sector is characterized by the presence of monopoly almost in all countries owned or regulated by government. Electricity has some special characteristics in comparison with other types of commodities. The main one is that it can't be stored rather consumed as it is generated and is very often sold in advance of production. Limitation of energy resources in addition to environmental factors requires the electric energy to be used more efficiently and more efficient power plants and transmission lines to be constructed. It is very important to correctly forecast the electricity demand. The fluctuating and unpredictable nature of wind is the major problem in harnessing wind energy. So, it is very important to improve the operation of wind turbine for its safety and better efficiency of wind energy harvesting system. Several methods have been used to improve the quality and efficiency of wind power system. An ANFIS model was used by many researchers to control factors affecting wind and predict the power output from wind to increase the efficiency of the WEHS.

1.5. Simulation Environment for Wind energy systems

For effective harvesting of wind energy System, the appropriate modeling of WECS is essential for the efficient utilization of electric energy to satisfy the needs of remote areas. As wind energy generation systems are highly nonlinear and complex it requires to be analyzed thoroughly. This requires an appropriate and suitable software tools and models which can be used for the design, analysis, optimization and economic planning. On literatures a number of software have been developed to assess the technical and economic potential of various renewable energy technologies to simplify the wind energy system design process and maximize the use of the renewable resources. The commonly used analysis software tools are Matlab/Simulink. Matlab/Simulink represent interactive tools for modeling, simulating, and analysing dynamic systems that have been successfully applied for nonlinear dynamics investigations in wind energy generation processes.

2. Work done on modeling of wind energy harvesting systems

Wind power generation has grown very rapidly in last two decades due to its lower cost and environmental problems. Wind is considered as the most viable energy source to fulfill the world's future energy demands. Therefore, a neuro fuzzy modeling techniques have been applied to improve the performance of wind energy system and predict the future power of the selected site. However, wind is totally weather dependent and the most difficult parameter to measure accurately due to its intermittent and unpredictable nature. Based on this, scholars used the neuro fuzzy techniques to model and control wind energy system to get the better result are given below.

Rasit Ata and Yagmur Kocyigit [11] have proposed an adaptive neuro-fuzzy inference system (ANFIS) model to predict the tip speed ratio (TSR) and the power factor of a wind turbine. The model is based on the parameters for LS-1 and NACA4415 profile types with 3 and 4 blades. In the development model, profile type, blade number, Schmitz coefficient, end loss, profile type loss, and blade number loss were taken as input variables, while the TSR and power factor were taken as output variables. After a successful learning and training process, the proposed model produced reasonable mean errors. The results indicate that the errors of ANFIS models in predicting TSR and power factor are less than those of the ANN method.

Oguz and Guney [12] have proposed ANFIS for the design of the output voltage and frequency control of a variable-speed wind generation system. Variable-speed wind power generation systems (VSWPGS) provide the opportunity to capture more power than fixed speed turbines and the variable-speed wind turbine output can be variable voltage and variable frequency for fluctuating wind speeds. The quality of output power can be improved if adequate controls are incorporated in the system. To bring the output voltage and frequency of system by means of control of blade pitch angle of wind turbine to a desirable value, ANFIS is designed based on the dynamic performance of VSWPGS. Control and dynamic performance analysis of VSWPGS is made depending on various loading situations.

Sathyavani and Harika Rachamalla [13] have proposed a unified wind energy conversion system as a way to create a more reliable, secure, efficient, safe, economic and environmentally friendly generation. They designed a simplified WEHS for the control of output voltage and frequency and to obtain high quality of power of the variable speed wind power generating system by using ANFIS. Variable speed control of wind turbine was performed by means of controlling of turbine blade pitch angle. The result confirmed the effectiveness of the proposed algorithm.

Ahmed Saleh et.al. [14] have proposed a hybrid neuro-fuzzy wind power prediction system. They used a wireless sensor network (WSN) to measure and transmit the required parameters for the prediction model at the operator centre. The parameters affecting wind farm output power considered were air temperature, wind speed, air density and air pressure. Taking all these factors into consideration will increase the prediction accuracy of the proposed model and the model is designed and tested using fuzzy rules with adaptive network. The proposed neuro-fuzzy model maintains good prediction accuracy and provides a useful qualitative description of the overall prediction system.

Dalibor Petkovic and ShahaboddinShamshirband [15] have proposed ANFIS method to build a wind turbine model with the best features by determining and analyzing the most influential factors to the produced wind energy. The ANFIS process for variable selection was implemented in order to detect the predominant variables affecting the converted wind energy. The main goal of the study was to determine how four parameters: blade pitch angle, rotor speed, wind speed and rotor radius, affect the wind turbine power coefficient. The ANFIS predictions can be compared against a linear regression model by comparing their respective root mean square values against checking data and noticed that the ANFIS model outperforms the linear regression model. The results indicated that of all the parameters examined, blade pitch angle is the most influential to wind turbine power coefficient prediction, and the best predictor of accuracy.

Dalibor Petkovi et.al [16] have proposed a novel intelligent controller based on the ANFIS to maintain the maximal output power of wind turbine. The application of ANFIS was proposed to control the continuously variable transmission (CVT) ratio to extract the maximal wind energy through the wind turbine. ANFIS structure has two inputs, effective wind speed and rotor speed and one output, the optimal wind turbine CVT ratio. The researchers used first-order Sugeno model with two inputs and fuzzy rules of Takagi and Sugeno's type. To improve the wind energy available in an unsteady wind speed regime, a wind generator equipped with continuously variable CVT was proposed. The ANFIS regulator adjusts the system speed, i.e. CVT ratio, for operating at the highest efficiency point. From the simulation result they concluded that the approach was effective and very useful for fast estimation of the maximal wind turbine power coefficient according to the main wind turbine parameters and wind speed variation as well.

Altab Hossain et.al. [17] have introduced a study on integrated control model using ANFIS for wind turbine power management strategy. The proposed ANFIS model has a total of five layers and two inputs *i.e.*, Reynolds number (RE) and wind velocity (WV), and one output which is wind power generation (WP) have been considered for the convenience of modeling. The linguistic variables: very low (VL), low (L), medium (M), high (H), and very high (VH) are used for the inputs and output. In the model, an ANN is employed to develop the fuzzy expert system in order to achieve a more realistic evaluation of wind power extraction. Demonstration was performed to investigate the effect of control strategy parameters on the system performance of the wind turbine and its power extraction. The result investigated the viability of the developed ANFIS model to evaluate power generation in wind turbine within high accuracy without needing to undergo laborious experimental work for a variety of environmental conditions with many uncertainties which can be non economical and time consuming.

Aoued Meharrar et.al. [18] have developed a model of variable speed wind-generator maximum power-point-tracking (MPPT) based on ANFIS. The model of ANFIS is used to predict the optimal speed rotation using the variation of the wind speed as the input. The WEHS employing a permanent magnet synchronous generator connected to a DC bus using a power converter is presented. The performance of the WEHS with the proposed ANFIS controller is tested for fast wind speed variation. They obtained the possibility of achieving maximum power tracking for the wind and output voltage regulation for the DC bus simultaneously with the ANFIS controller and has better response compared to fuzzy logic model. The results also proved the good response and robustness of the control system proposed.

Dalibor Petkovic´et.al. [19] have constructed an ANFIS model for wind turbine noise levels in regard to wind speed and sound frequency. The sources of aerodynamic noise can be divided into tonal noise, inflow turbulence noise and airfoil self-noise. Wind turbine noise is one of the major obstacles for the widespread use of wind energy. Noise annoyance caused by wind turbines has become an emerging problem in recent years, due to the rapid increase in number of wind turbines, triggered by sustainable energy goals set forward at the national and international level. The study analyzed noise level of wind turbines in relation to wind speed and sound frequency by the adaptive neuro-fuzzy methodology. The obtained results indicated that ANFIS method predicts wind turbine noise level with higher estimation accuracy and shorter computation time.

Asghar et.al. [4] have proposed a novel control algorithm based on ANFIS to estimate the wind turbine power coefficient as a function of tip-speed ratio and pitch angle. An attempt was made to retrieve a relationship between power coefficient, tip speed ratio (TSR) and collective pitch angle for national renewable energy laboratory (NREL) offshore 5 MW baseline wind turbine by using FAST code which is a computer aided engineering tool with the capability of modeling 3-bladed wind turbines. They conducted experiment during online operation and collect input/output data to design ANFIS. The proposed model trains FIS and enables it to accurately estimate the power coefficient for given values of TSR and pitch angle. The least square algorithm is used to train the system in forward pass and back propagation gradient decent algorithm in backward pass. The results prove the ability of proposed model to estimate the power coefficient were very efficient and accurate as compared to other methods. The values predicted by ANFIS are very close to the real data.

Asghar et.al. [20] have proposed a hybrid intelligent learning based ANFIS for online estimation of effective wind speed from instantaneous values of wind turbine tip speed ratio (TSR), rotor speed and mechanical power. To design ANFIS, the input/output data samples are collected by conducting experiments during online operation of national renewable energy laboratory (NREL) offshore 5 MW baseline wind turbine. The ANN adjusts the parameters of fuzzy membership functions (MFs) using hybrid optimization method (least square method and back propagation gradient decent method) to accurately estimate the effective wind speed without using any mechanical wind speed sensor. The estimated value of effective wind speed and optimal TSR are further utilized to design the optimal rotor speed estimator for MPPT of variable-speed wind turbine (VSWT). Both estimators were implemented in MATLAB and their performance was investigated for NREL offshore 5 MW baseline wind turbine. The simulation results show the effectiveness of proposed method.

Dalibor Petkovic et.al. [21] have proposed ANFIS to estimate optimal power coefficient value of the wind turbines. As wind speed vacillates rapidly, the quality of energy produced becomes an important problem in wind energy conversion plants. Neural network in ANFIS adjusts parameters of membership function in the fuzzy inference system (FIS) whereas the backpropagation learning algorithm is used for training this network. The paper investigated the impact of the variation in the wind speed, blade pitch angle, rotor tip speed and rotor radius of the wind turbine on the performance of the wind energy system. The main advantage of designing the ANFIS coordination scheme is to estimate wind turbine power coefficient as the main turbine parameter according to wind speed, blade pitch angle, and rotor tip speed and rotor radius. In their work, the first-order Sugeno model with two inputs and fuzzy rules of Takagi and Sugeno's type was used. The simulation results show the effectiveness of the developed method.

Vlastimir Nikolic et.al. [22] have proposed an ANFIS methodology to estimate wind turbine noise in regard of wind speed at different heights and for different sound frequency. ANFIS was modeled to estimate the WT noise level in regard to wind speed at 10 m height, wind speed at 80 m height (hub height) and sound frequency. In other words the ANFIS network has three inputs. Two membership functions are used for each of the input in order to fuzzify the input values. Bell-shaped membership functions are chosen in the study as the functions have the best generalization capabilities. Predictive performances of proposed model were presented as root means square error (RMSE), coefficient of determination and Pearson coefficient. ANFIS predictive model results for wind turbine noise estimation for different wind speed at 10 m and 80 m show a very good agreement with the actual values of the wind turbine characteristics. This observation can be confirmed with very high value of coefficient of determination. The number of either overestimated or underestimated values is limited.

Ahmed Abdullah et.al [23] have proposed a hybrid neuro-fuzzy wind power prediction system. They used wireless sensor network (WSN) to measure and transmit the required parameters for the prediction model at the operator center. Those parameters are air temperature, wind speed; air density and air pressure that affecting wind farm output power. The consideration of all these factors were increased the prediction accuracy of the proposed model. The proposed prediction model was designed using fuzzy rules with adaptive network. To determine the maximum number of fuzzy rules, the clustering of the data using modified Fuzzy C-Means (FCM) was used to implement hybrid optimization method. For training the prediction model, four subset data could be selected to cover all seasons of the year. Considering all these factors increases the prediction accuracy of the proposed model.

Rasit ATA [5] have developed an ANFIS model for predicting the power factor of a wind turbine based on the parameters involved for NACA 4415 and LS-1 profile types with 3 and 4 blades. In the study, power factor o wind turbine was predicted using ANFIS from seven input variables. For the developed model, profile type, blade number, Schmitz coefficient, end loss, profile type loss, and blade number loss were taken as input variables, while the power factor was taken as output variable for the two profile types. A hybrid ANFIS algorithm based on the Sugeno system improved by Jang [24] was used for acquiring optimal output data in the study. The results on a testing data are compared with the ANN and the conventional approach in estimating the power factor. The results indicate that the ANFIS model is found to be more successful than the ANN approach in estimating the power factor.

Arul et.al. [25] have proposed a neuro fuzzy control method for extracting the maximum power in a WECS which adjusts the blade pitch angle of the wind turbine as well as control the grid side converter to attain maximum efficiency. The pitch angle control is made to control the wind flow around the turbine blades by controlling the moment spent on the turbine shaft. The wind speed is estimated from the measured generator electrical power while taking into account the power losses in the Wind Turbine Generator (WTG) and the dynamics of the WTG shaft system. The controller tracks the generator speed with the wind velocity and adjusts the pitch angle to extract the maximum power. A second neuro-fuzzy controller gives robust speed control against wind gust and turbine oscillatory torque. The complete control system has been developed, analyzed, and validated by simulation study using MATLAB/SIMULINK software. Simulation results show that the performance of the control algorithm compares well with the conventional methods.

Arul et.al. [26] have presented a neuro fuzzy control scheme for extracting maximum power from a variable speed wind turbine. Neuro-fuzzy controller adjusts the angular speed so that the turbine power coefficient converges to its maximum value in the steady state. They have shown that the turbine power output depends nonlinearly on its angular speed and the wind speed. The neuro fuzzy controller makes the wind turbine speed to be tuned fine until it gets the error free output which the user need. As a result of controlling of the wind turbine blade pitch angle, it is determined from the simulation results that the output electrical magnitudes of variable speed wind power generation system (*VSWPGS*) (voltage, current, frequency and power) reach to desirable values within 1.5 seconds. It is observed from simulation result that continuous situation error is close to zero in continuous operation. As the load of consumers fed from VSWPGS differs in every hour of a day, coefficients of the conventional controller must be readjusted depending on changing load situations. For this reason, in case of changing consumer load situations, the turbine blade pitch angle is adaptively adjusted to keep the terminal voltage and frequency within permitted tolerance values.

Abdel Ghani Aissaoui et.al. [27] have develop the overall model of the WECS structure based on induction generator (IG), and propose a study of the electrical parts (induction machine and static converter). An adaptive fuzzy power controller was proposed in order to control the power generated by the WECS and transmitted to the grid. They described the different structures of wind turbines based on the IG, established a model of the wind energy conversion chain, and designed a control strategy using the concept of vector control. They have subsequently built a device for controlling the chain of the proposed conversion by using fuzzy logic technique. The overall system was tested for a variable wind speed using PI controller. A simulation results show that the possibility of extracting the maximal power from the wind, the control of the power generated to the grid by controlling the rotor voltages and the high performances of the controller based on fuzzy logic techniques.

Bekhada Hamane et.al. [28] have proposed a study analysis of a WECS based on a doubly fed induction generator (DFIG) connected to the electric power grid. The aim of the paper was to present the complete modeling and simulation analysis and performance comparison of classical PI and Fuzzy-PI controller for wind turbine driven DFIG in terms of tracking and robustness with respect to the wind fluctuation as well as the impact on the quality of the energy produced. A vector control with stator flux orientation of the DFIG is also presented to control both the active and reactive powers between the stator and the grid, and further to achieve maximum wind energy capturing. To show the effectiveness of the control method performances analysis of the system are analyzed and compared by simulation in terms of the performances of the machine. The results have shown that with the Fuzzy-PI controller, the settling time is reduced considerably, peak overshoot of values are limited and oscillations are damped out faster compared to the conventional PI Controller. Thus they conclude from test results that the Fuzzy-PI Controller is more powerful than the classical one.

Cameron Potter and Michael Negnevitsky [29] have presents an application of an ANFIS to power forecasting problems. The forecasts are used to reduce the difference between the power available and the power consumed. The need for accurate forecasts is increasing as power markets are becoming more competitive. The paper gives a brief overview of the issues facing power system forecasting and proposed the use of ANFIS to perform short term scheduling. The operation of a power system is usually divided into four different categories: long term, medium term, short term and real-time. The paper investigated short-term forecasting for a power system. It especially focuses on a sub-class referred to as *very* short term forecasting. Very short term forecasting is predominantly focused on predicting the value of the next period of an applicable data set. In this instance, that period will be the operating cycle of the National Electricity Market of Australia. The result shows that ANFIS is an excellent technique for power forecasting and is likely to work very well for other forecasting applications as well.

S. Krishnama Raju and G. N. Pillai [30] have proposed a novel control strategy using type-2 FLC for a DFIG based wind turbines connected to a distributed network. Type-2 FLSs are described with a three dimensional fuzzy MF that includes a footprint of uncertainty (FOU). The controllers are designed for the converters of DFIG to examine the effect of FOU in the membership function for handling the system uncertainties. The designed controller is implemented for real time simulations and interfaced with the RTDS/RSCAD in hardware in the loop (HIL) configuration using analog signals of control error. The performance is evaluated on IEEE-34 bus test system for steady state and dynamic behavior under three phase fault, load loss and variable wind speed conditions. The simulation results showed a significant improvement in the power oscillation damping and voltage profile of the distributed network compared to that of type-1 FLC, under various uncertainties. The proposed strategy is able to give a satisfactory performance, in variable wind speed conditions, without the need of retuning the controller parameters.

Rustom Mamlook et.al. [31] have used the neuro-fuzzy approach to determine the most suitable options for electricity production and provide solutions to some of the current or future energy issues that Jordan faces. The options include nuclear, solar, wind, or hydroelectric power generation systems. The researchers aimed to direct the energy decision-makers in Jordan to the most appropriate system for electric power generation. The neuro-fuzzy logic decision maker (NFDM) selection of best electrical production option(s) in Jordan was applied according to their costs and benefits. NFDM uses minimum and maximum operations, which are easier and faster than average and sum operations that are used by other methods. The result indicated that the best preferable option was to use solar system fallowed by hydro, wind, or all these three options could be used to produce electricity in Jordan with minimum cost and optimum benefits in terms of issues related to availability of fuel, national economy, social benefits, and safety. Therefore, the next two options are the use of hydro and wind systems. The worst option is found to be nuclear due to its high initial cost and safety factor. It is followed by fossil fuels.

Dalibor Petkovic et.al. [32] have proposed ANFIS to estimate wind speed and direction percentage distribution. Then the ANFIS model would estimate wind farm power production as function of wind speed and direction percentage distribution. Fuzzy logic tool kit in MATLAB was utilized for the whole methodology of preparing and assessment of fuzzy deduction framework. The primary goal of the study was to make a model which builds the association between wind speed and wind course at the pole with generation yield of the wind farm. Later by the same methodology they anticipate the wind homestead power processing as capacity of wind velocity and heading. In their work, the first-order Sugeno model with two inputs and fuzzy IF–THEN controls of Takagi and Sugeno's sort was used. The reenactment outcomes exhibited in the paper demonstrate the adequacy of the created technique.

Shahaboddin Shamshirband et.al. [33] have proposed a novel algorithm based on ANFIS for wind speed estimation in wind-power generation systems. The ANFIS method was based on offline training of the input–output samples. The main aim of their work were to express wind speed V_e in relation to the three wind turbine parameters: blade pitch angleβ, rotor speed and power coefficient C_p for rotor radius R = 75m: $V_e(C_p, \beta, \Omega_r)$. To do this, three ANFIS networks with different inputs were investigated to determine which combinations of the inputs have the smallest regression error. ANFIS-1 has two inputs, rotor speed and wind turbine power coefficient, ANFIS-2 has also two inputs, blade pitch angle and rotor speed, and ANFIS-3 has three inputs, blade pitch angle, rotor speed and wind turbine power coefficient. All three ANFIS networks with different inputs were investigated to determine which combinations of the inputs have the smallest regression error. First-order Sugeno ANFIS model with fuzzy IF–THEN rules of Takagi and Sugeno's type was used. The simulation results presented show the effectiveness of the developed method.

Yiannis A. Katsigiannis et.al. [34] have proposed a method based on Artificial Neural Network (ANN) in order to improve the predictions of an existing neuro-fuzzy wind power forecasting model taking into consideration the evaluation results from the use of this wind power forecasting tool. The output of an existing neuro-fuzzy wind power prediction tool is used as input to the proposed method and trains the ANN using the results from the evaluation of the forecasting model. The output of the ANN is a new and improved wind power forecast. In addition, an 85% confidence interval was provided to the operators for this improved wind power forecast. It was shown that the proposed ANN model exploits the past performance of the neuro-fuzzy model and provides more accurate wind power forecasting values. The proposed method offers significant improvements in all crucial information for power system operators, concerning wind power prediction and its uncertainty estimation, providing narrower confidence intervals for the predicted wind power.

M. Mohandes et. al [35] have proposed a clustering based neuro-fuzzy method to estimate wind speed at high altitudes based on measurements at lower heights in Juaymah city of Saudi Arabia for a period of 17 months between July 01, 2006 and November 30, 2007. They used ANFIS for the estimation of wind speed profile and the training of the model was performed in MATLAB environment. The ANFIS model is trained on the first 3 wind speed values at heights 10, 20 and 30 m to predict wind speed at 40 m. Similarly, the trained ANFIS model is tested using the wind speed values at heights 20, 30, and 40 m to predict at 50 m. This process continues with using the newly generated values to predict the values at higher heights until 100 m. The model estimated wind speed at 40 m based on measured data at 10, 20, and 30 m has 3% mean absolute percent error when compared with measured wind speed at height 40 m. This close agreement between estimated and measured wind speed at 40 m indicates the viability of the proposed method. The comparison with the 1/7th law and experimental wind shear method further proofs the suitability of the proposed method for generating wind speed profile based on knowledge of wind speed at lower heights.

Hugo M. I. Pousinho et.al [36] have proposed an ANFIS for short-term wind power forecasting in Portugal, which is a new contribution. The proposed approach was compared with persistence, auto regressive integrated moving average (ARIMA) and NN approaches, to demonstrate its effectiveness regarding forecasting accuracy and computation time. The ARIMA approach is developed using SPSS software and the NN approach is developed using MATLAB. Parameter estimation was performed with the aid of these softwares. The configuration considered corresponds to an ARIMA (1, 2, 1). The proposed ANFIS method uses the combination of least-squares method and backpropagation gradient descent method to identify parameters of Sugeno-type FIS. The configuration considered corresponds to a three-layered feed-forward network which have one input layer with four units, one hidden layer with nine units considering hyperbolic tangent sigmoid transfer function, and one output layer with one unit considering pure linear transfer function. The proposed NF approach provides smaller errors compared with ARIMA and NN approaches. Hence, the proposed NF approach provides a powerful tool of easy implementation for short-term wind power forecasting.

Dalibor Petkovic [37] has used ANFIS to predict the probability density distribution of wind speed. Probability density distribution of wind speed is very important information needed in the assessment of wind energy potential. The Weibull distribution is a two-parameter function used to fit the wind speed frequency distribution. The Weibull function provides a convenient representation of the wind speed data for wind energy calculation purposes. The ANFIS model was designed based on three methods of estimating the parameters of the Weibull wind speed distribution: two variations of the maximum likelihood method (i.e. maximum likelihood and modified maximum likelihood) as well as the popular graphical method. In other words the ANFIS model should estimates average two-parameter function of Weibull distribution based on the exciting methods. Three ANFIS models results estimation and prediction accuracy were calculated using three statistical indicators i.e. root means square error (RMSE), coefficient of determination(R^2) and Pearson coefficient(r) to demonstrate the advantages of the proposed ANFIS model on a more definite and tangible basis. Accuracy results measured indicate that ANFIS predictions were with high predictive accuracy and concluded that it was very suitable and efficient method in order to estimate Weibull parameters for wind energy applications.

Yishuang Qi and Qingjin Meng [38] have applied the theory of fuzzy control and PID control to the control of generator speed and blade pitch angle of wind turbine. Fuzzy PID control theory was applied to wind turbine pitch control, through the stator voltage control at low speed and the blade pitch angle control at high speed so that the generators works in the best condition. By comparison with the traditional PI controller, this method can accelerate system response speed, improve the accuracy and improve variable pitch wind turbine control effect. Wind turbine model was set up in MATLAB and the simulation is done in simulink to verify the feasibility of this method.

Ramadoni Syahputra and Indah Soesanti [39] have described the way doubly-fed induction generator (DFIG) was controlled using ANFIS method. The wind turbine driven by doubly-fed induction generator is a part of distributed generation which feeds AC power to the distribution network. The ANFIS model makes use of rotor reference frame using dynamic vector approach for machine model. It is applied to rotor side converter for controlling active power and regulating voltage of wind power. The obtained result confirmed the excellent performance of ANFIS control unit as improving power quality and stability of wind turbine.

Yuksel Oguz and Irfan Guney [40] have proposed adaptive neuro-fuzzy inference system for the design of the output voltage and frequency control of a variable-speed wind power generation system (VSWPGS). VSWPGS provide the opportunity to capture more power than fixed speed turbines and the variable-speed wind turbine output can be variable voltage and variable frequency for fluctuating wind speeds. The quality of output power can be improved if adequate controls are incorporated in the system. To bring the output voltage and frequency of system by means of control of blade pitch angle of wind turbine to a desirable value, an ANFIS was used in the paper. ANFIS is designed based on the dynamic performance of VSWPGS. Control and dynamic performance analysis of VSWPGS is made depending on various loading situations.

Yuksel Oguz et.al. [41] have realized dynamic modeling of the hybrid wind-gas power generation system (HWGPGS) by using the MATLAB/Simulink program for the purpose of meeting the electric energy needs of small settlement units far from city centers or energy distribution networks. ANFIS is used to ensure electrical output magnitudes of the hybrid power generation system at a desired operating performance. It automatically adjusts the blade pitch angle of WPGS and tribune speed of GPGS in every changing load situation. In the simulation studies, almost the same dynamic behavior of real wind-gas generation units is observed. All the electrical output magnitude values of the hybrid power generation system with ANFIS control reach to desired values within 1.5-2 s under continuous operational mode.

Gayadhar Panda et.al. [42] have presented with a novel approach of artificial intelligence (AI) technique called Hybrid Neuro-Fuzzy (HNF) approach for an Automatic Generation Control (AGC) whose main objective is to balance the total system generation against system load losses so that the desired frequency and power interchange with neighboring systems is maintained. Any mismatch between generation and demand causes the system frequency to deviate from its nominal value and this may lead to system collapse. This necessitates a very fast and accurate controller to maintain the nominal system frequency.

Mohamed M. Ismail and Ahmed F. Bendary [43] have focused on studying of using Double Fed Induction Generator (DFIG) as a wind turbine connected to a grid subjected to various types of fault. ANFIS controller was used for protection of DFIG during faults. Due to its various advantages especially low generation cost, DFIG had been widely used as a wind turbine generator and becomes the most important and promising sources of renewable energy. The paper presented a new technique of crowbar implementation using ANFIS controller. Crowbar is a kind of protection used for wind turbine generator protection. The response of DFIG during different types of faults is improved by adapting the parameters of PI controllers of the voltage regulator using fuzzy logics. Therefore, the contribution of their work through using ANFIS is achieved to reach two main goals, first to detect and protect the rotor winding of wind turbine generator when subjected to fault. Second to implement a standby DC capacitor in operation in case of the original capacitor is damaged due to voltage rise on it during fault subjection. The proposed technique shows promising results using the simulation model.

Ramji Tiwari and Ramesh Babu.N [44] have presented a comparative analysis of different control methods to extract the maximum power from Permanent Magnet Synchronous Generator (PMSG) based wind Energy Conversion System (WECS) under different wind speed condition. The WECS consists of a wind turbine, a PMSG and a DC/DC converter which is connected to a DC load. Three Maximum Power Point Tracking (MPPT) control technique: Proportional Integral (PI) control, Perturb and Observe (P&O) method and Fuzzy Logic Controller (FLC) are compared. The parameters considered for analyzing the efficiency of the MPPT controller is the output DC voltage and power across the load. The steady state voltage and the dynamic response of the system under different wind speed are considered to justify the overall efficiency of the controllers. The performance of each controller under variable wind speed was analyzed and it was verified that FLC based controller is more efficient and reliable than PI and P&O based controller in terms of stability, faster tracking ability and fluctuations. Hence, it is concluded that the FLC based MPPT method is the best option for standalone WECS. The PI controller fails to track the non linearity of the wind speed thus providing poor output power whereas the P&O based technique is suitable for the condition where the system is stable of with minimum variance.

Dalibor Petkovic [45] has presented the study to analyze relationship between wind farm efficiency, power production, cost, cost per power unit and the number of wind turbines in wind farm. He proposed ANFIS strategy to estimate wind farm efficiency according to turbines number in wind farm. The two primary objectives of optimal wind farm planning are to minimize the cost of energy and to maximize the net energy production or to maximize wind farm efficiency. The optimal placement of wind turbines in a wind farm and the optimal number of wind turbines will maximize the total wind energy extraction efficiency of a wind farm. A simulink model was developed in MATLAB with the ANFIS network for the wind farm power production, total cost, cost per power unit and wind farm efficiency estimation. The main point of interest of planning the ANFIS coordination plan is to estimate wind farm efficiency as one very important parameter for overall produced energy according to number of wind turbines.

Shahaboddin Shamshirband et.al. [46] have proposed ANFIS method to predict the wake power deficit. They have presented and tested the approach for developing an alternative method to predict wake effect power deficit. The unique approach of ANFIS method has been validated against the most commonly used wake models. The ANFIS approach predicts the faster distribution of wake effect than the analytical methods. This new ANFIS method is compared with three most common methods, N.O. Jensen wake model, Eddy Viscosity Model and G.C. Larsen model. The ANFIS model should estimates average wake effect power deficit in wind farm based on the established analytical models. The results show that the ANFIS can be an alternative to the wake models. It is worth to indicate that superiority of ANFIS method over other methods can be obviously observed with estimation capability of wake distribution. Then it is concluded that ANFIS method is very suitable and efficient in order to estimate wake effect for wind energy applications. The simulation results presented show the effectiveness of the developed method.

3. Gap Analysis

System modeling based on conventional mathematical tools such as differential equations is not well suitable for dealing with ill-defined and uncertain systems. However, fuzzy inference system employing fuzzy if- then rules can model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analyses. As there is no standard methods exist for converting human knowledge or experience into the rule base and database of a fuzzy inference system and due to a need for effective methods for tuning the membership functions (MF's) researchers combine it with neural network to minimize the output error measure or maximize performance index. Researchers suggest ANFIS, which can serve as a basis for constructing a set of fuzzy rules with appropriate membership functions to generate the stipulated input-output pairs. Since wind energy harvesting systems are governed by highly nonlinear functions, ANFIS can effectively model such types of systems appropriately as compared to neural networks.

After an extensive review of literatures on modeling of wind energy harvesting system using neuro-fuzzy method, the following gaps are observed:

a) The models developed so far mainly focused on controlling specific input and output parameters. This may limit the performance of the proposed methods.

b) The model developed so far would not focus on the cost minimization rather it was on power maximization.

c) In some studies the performance evaluation of the proposed method has not been evaluated.

d) Further attempts for developing a model for wind energy harvesting system for meeting the energy needs of the remote society are also limited. Most of them focus on urban power.

4. Conclusion and Future Scope

The paper was motivated by the focus on utilizing renewable energy resources aiming to fulfill increasing energy requirements and mitigate the climate change impacts of fossil fuels. While most renewable energy sources are free, the technology used to convert such resources is not and there is an increasing focus on improving the conversion economy and efficiency. Due to fast depletion of conventional energy sources and continuously increasing energy demand and in the context of environmental impact, scholars have been encouraged intensive research for new, more efficient, and green power plants with advanced technology. Nowadays, an environmental protection concerns are increasing in the whole world, which was the cause for both new energy and clean fuel technologies are being intensively pursued and investigated. Most of the renewable energy from wind, micro-hydro, tidal, geothermal, biomass, and solar are converted into electrical energy to be delivered either to the utility grid directly or isolated loads.

There is also high imbalance of electricity distribution among countries and within the country everywhere. The magnitude of this imbalance distribution was wide in developing countries. Here in addition to low coverage there is imbalance distribution and needs great attention to compromise the gap observed. This survey paper compiled brief summary of wind energy systems and different papers are reviewed. All scholars agreed that to full fill the exponentially increasing energy demand all over the world, renewable energy systems are the most technologies to be encouraged. In order to get sufficient energy with affordable project through the life time of the system, proper design and modeling of all the component system is important. These involved components of WEHS components are explained. Lastly simulation tools which are used to model, simulation and analysis based on the raw of input data inserted by user are discussed.

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6. References

[1] Rasit ATA and Numan Sabit Cetin., "Neural prediction of power factor in wind turbines.," *IU-Journal of Electrical & Electronics Engineering.*, vol. 7, no. 2, pp. 431-438, 2007.

[2] Global Wind Energy Council. (2017, April) www.gwec.net/global-figures/graphs/. [Online]. http://www.gwec.net/global-figures/graphs/

[3] M., Shafiqur Rehman, and S. M. Rahman. Mohandes, "Estimation of wind speed profile using adaptive neuro-fuzzy inference system (ANFIS).," *Applied Energy*, vol. 88, no. 11, pp. 4024-4032, 2011.

[4] Aamer Bilal, and Xiaodong Liu. Asghar, "Estimation of wind turbine power coefficient by adaptive neuro-fuzzy methodology.," *Neurocomputing.*, vol. 238 , pp. 227-233, 2017.

[5] A. T. A. Rasit, "An adaptive neuro-fuzzy inference system approach for prediction of power factor in wind turbines.," *IU-Journal of Electrical & Electronics Engineering.*, vol. 9, no. 1, pp. 905-912, 2009.

[6] Carlos M., and Jose F. Espiritu. Ituarte-Villarreal, "Optimization of wind turbine placement using a viral based optimization algorithm.," *Procedia Computer Science* , vol. 6, 2011.

[7] M. N. Y. Murthy, "A review on power electronics application on wind turbines.," *International Journal of Research in Eng. &Technology, 2(11), 09.*, vol. 2, no. 11, p. 09, 2013.

[8] Omar, E. Abdulhadi, and Y. El-Tous. Badran, "Fuzzy Logic Controller for Predicting Wind Turbine Power Generation. ," *International Journal of Mechanical and Materials Engineering.*, vol. 6, no. 1, pp. 51-66, 2011.

[9] Vahid, and Hassan Nikkhajoei. Oghafy, "Maximum power extraction for a wind-turbine generator with no wind speed sensor.," *In Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century.* , pp. 1-6, 2008.

[10] Thomas, and Lennart Soder. Ackermann, "An overview of wind energy-status 2002.," *Renewable and sustainable energy reviews.*, vol. 6, no. 1, pp. 67-127, 2002.

[11] R. Ata and Y. Kocyigit, "An adaptive neuro-fuzzy inference system approach for prediction of tip speed.," *Expert Systems with Applications*, vol. 37, 2010.

[12] Yuksel, and Kamil Rifat Irfan Guney. Oguz, "Adaptive neuro-fuzzy inference system to improve the power quality of variable-speed wind power generation system.," *Turkish Journal of Electrical Engineering & Computer Sciences*, vol. 18, no. 4, 2010.

[13] B. Sathyavani and Harika Rachamalla, "Sustainable Architecture of Wind Energ yConversion System based on Neuro-Fuzzy Approach," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 5, no. 8, 2016.

[14] Ahmed E., Mohamed S. Moustafa, Khaled M. Abo-Al-Ez, and Ahmed A. Abdullah. Saleh, "A hybrid neuro-fuzzy power prediction system for wind energy generation.," *International Journal of Electrical Power & Energy Systems* , vol. 71, 2016.

[15] D. Shamshirband, S. Petkovic, "Soft methodology selection of wind turbine parameters to large affect wind energy conversion.," *International Journal of Electrical Power & Energy Systems.*, vol. 69, pp. 98-103, 2015.

[16] Dalibor, Zarko Cojbasic, Vlastimir Nikolic, Shahaboddin Shamshirband, Miss Laiha Mat Kiah, Nor Badrul Anuar, and Ainuddin Wahid Abdul Wahab. Petkovic, "Adaptive neuro-fuzzy maximal power extraction of wind turbine with continuously variable transmission.," *Energy*, vol. 64, pp. 868-874, 2014.

[17] Altab, Ramesh Singh, Imtiaz A. Choudhury and Abu Bakar. Hossain, "Energy efficient wind turbine system based on fuzzy control approach..," *Procedia Engineering* , vol. 56, pp. 637-642, 2013.

[18] Tioursi M, Hatti M, Stambouli AB. Meharrar A, "A variable speed wind generator maximum power tracking based on adaptative neuro-fuzzy inference system. ," *Expert Systems with Applications.*, vol. 38, no. 6, pp. 7659-7664, 2011.

[19] Shahaboddin, Dalibor Petkovic, Roslan Hashim, and Shervin Motamedi. Shamshirband, "Adaptive neuro-fuzzy methodology for noise assessment of wind turbine.," *PloS one*, vol. 9, no. 7, p. p.e103414, 2014.

[20] A. B. , & Liu, X. Asghar, "Adaptive neuro-fuzzy algorithm to estimate effective wind speed and optimal rotor speed for variable-speed wind turbine.," *Neurocomputing 272.*, pp. 495-504, 2018.

[21] Dalibor, Zarko Cojbasic, and Vlastimir Nikolic. Petkovic, "Adaptive neuro-fuzzy approach for wind turbine power coefficient estimation.," *Renewable and Sustainable Energy Reviews.*, vol. 28, pp. 191-195, 2013.

[22] Vlastimir, Dalibor Petkovic, Lip Yee Por, Shahaboddin Shamshirband, Mazdak Zamani, Žarko Ćojbašić, and Shervin Motamedi. Nikolic, "Potential of neuro-fuzzy methodology to estimate noise level of wind turbines.," *Mechanical Systems and Signal Processing*, vol. 66, pp. 715-722, 2016.

[23] A., Saleh, A., Moustafa, M., & Abo-al-Ez, K. Abdullah, "A proposed Framework for a Forecasting System of Wind Energy Power Generation.," *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)*, vol. 3, no. 4, 2014.

[24] J.S. Jang, "ANFIS: adaptive-network-based fuzzy inference system. ," *IEEE transactions on systems, man, and cybernetics.*, vol. 23, no. 3, pp. 665-685, 1993.

[25] I., Dr M. Karthikeyan, Dr N. Krishnan, and Dr N. Albert Singh. Arul, "Neuro Fuzzy Based Maximum Power Tracking Control Algorithm In Wind Energy Conversion Systems.," *International Journal of Electrical Engineering & Technology (IJEET).*, vol. 3, no. 2, pp. 285-293, 2012.

[26] I. DRM Karthikeyan, DRN Krishnan, and K. MAaniraj. Arul, "Extracting Maximum Power Optimization in Wind Turbine Using Neuro Fuzzy Logic Control.," *IOSR Journal of Electrical and Electronics Engineering*, vol. 6, no. 1, 2012.

[27] Abdel Ghani, Ahmed Tahour, Mohamed Abid, Najib Essounbouli, and Frederic Nollet. Aissaoui, "Power control of wind turbine based on fuzzy controllers.," *energy proceding.*, vol. 42, pp. 163-172, 2013.

[28] B., M. Benghanemm, A. M. Bouzid, A. Belabbes, M. Bouhamida, and A. Draou. Hamane, "Control for variable speed wind turbine driving a doubly fed induction generator using Fuzzy-PI control.," *Energy Procedia.*, vol. 18, pp. 476-485, 2012.

[29] Cameron, and M. Negnevitsky. Potter, "Short term power system forecasting using an adaptive neural-fuzzy inference system. ," *In Australian andNew Zealand intelligent information systems conference (ANZIIS)*, vol. 8, pp. 465-470, 2003.

[30] S. Krishnama, and G. N. Pillai. Raju, "Design and implementation of type-2 fuzzy logic controller for DFIG-based wind energy systems in distribution networks. ," *IEEE Transactions on Sustainable Energy.*, vol. 7, no. 1, pp. 345-353, 2016.

[31] Rustom, Bilal A. Akash, and Mousa S. Mohsen. Mamlook, "A neuro-fuzzy program approach for evaluating electric power generation systems.," *Energy.*, vol. 26, no. 6, pp. 619-632, 2001.

[32] Dalibor, Shahaboddin Shamshirband, Nor Badrul Anuar, Sareh Naji, Miss Laiha Mat Kiah, and Abdullah Gani. Petkovic, "Adaptive neuro-fuzzy evaluation of wind farm power production as function of wind speed and direction.," *Stochastic environmental research and risk assessmen*, vol. 29, no. 3, pp. 793-802, 2015.

[33] Shahaboddin, Dalibor Petkovic, Nor Badrul Anuar, Miss Laiha Mat Kiah, Shatirah Akib, Abdullah Gani, Zarko Cojbasic, and Vlastimir Nikolic. Shamshirband, "Sensorless estimation of wind speed by adaptive neuro-fuzzy methodology.," *International Journal of Electrical Power & Energy Systems.*, vol. 62, pp. 490-495., 2014.

[34] Yiannis, Antonis Tsikalakis, Pavlos Georgilakis, and Nikos Hatziargyriou. Katsigiannis, "Improved wind power forecasting using a combined neuro-fuzzy and artificial neural network model. ," *Advances in Artificial Intelligence.*, pp. 105-115, 2006.

[35] M., S. Rehman, and S. M. Rahman. Mohandes, "Estimation of wind speed profile using adaptive neuro-fuzzy inference system (ANFIS). ," *Applied Energy.*, vol. 88, no. 11, pp. 4024-4032, 2011.

[36] Hugo MI, Victor MF Mendes, and João PS Catalão. Pousinho, "Application of adaptive neuro-fuzzy inference for wind power short-term forecasting. ," *IEEJ Transactions on Electrical and Electronic Engineering.*, vol. 6, no. 6, pp. 571-576, 2011.

[37] Dalibor. Petkovic, "Adaptive neuro-fuzzy approach for estimation of wind speed distribution.,"

International Journal of Electrical Power & Energy Systems., vol. 73, pp. 389-392, 2015.

[38] Yishuang, and Qingjin Meng. Qi, "The application of fuzzy PID control in pitch wind turbine.," *Energy Procedia.*, vol. 16, pp. 1635-1641, 2012.

[39] Ramadoni, and Indah Soesanti. Syahputra, "DFIG Control Scheme of Wind Power Using ANFIS Method in Electrical Power Grid System. ," *International Journal of Applied Engineering Research* , vol. 11, no. 7, 2016.

[40] Yuksel, and Kamil Rifat Irfan Guney. Oguz, "Adaptive neuro-fuzzy inference system to improve the power quality of variable-speed wind power generation system.," *Turkish Journal of Electrical Engineering & Computer Sciences*, vol. 18, no. 4, 2010.

[41] Yuksel, Irfan Guney, and Hasan Erdal. Oguz, "Modeling of hybrid wind-gas power generation system and adaptive neuro-fuzzy controller to improve the system performance.," *Computer Applications in Engineering Education*, vol. 18, no. 4, 2010.

[42] Gayadhar, Sidhartha Panda, and Cemal Ardil. Panda, "Hybrid neuro fuzzy approach for automatic generation control of two–area interconnected power system.," *International Journal of Computational Intelligence.*, vol. 5, no. 1, 2009.

[43] Mohamed M., and Ahmed F. Bendary. Ismail, "Protection of DFIG wind turbine using fuzzy logic control.," *Alexandria Engineering Journal.*, vol. 55, no. 2, pp. 941-949, 2016.

[44] Ramji, and N. Ramesh Babu. Tiwari, "Fuzzy logic based MPPT for permanent magnet synchronous generator in wind energy conversion system.," *IFAC-Papers OnLine.*, vol. 49, no. 1, pp. 462-467, Jan 2016.

[45] Dalibor. Petkovic, "Estimation of wind farm efficiency by ANFIS strategy.," vol. 7, 2016.

[46] Shahaboddin, Dalibor Petkovic, Roslan Hashim, Shervin Motamedi, and Nor Badrul Anuar. Shamshirband, "An appraisal of wind turbine wake models by adaptive neuro-fuzzy methodology.," *International Journal of Electrical Power & Energy Systems.*, vol. 63, pp. 618-624, 2014.