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Control Strategies of Wind Power

Dikonda Sai Sri Ram[1], Chitikina Bharat Sai[2]
[1, 2]3rd Year Department of Electrical and Electronics Engineering, Sasi Institute Of Technology And Engineering

Abstract: The electrical energy harnessed from wind energy has been identified as one of the most reliable and readily available in abundance sources of renewable. The design and development of wind energy generating systems to achieve the desired quality and quantity of power generation is not a simple task for the power engineers. The wind power has been identified as one of the most cost effective ways to generate clean electricity from renewable sources. The wind turbine prime mover i.e. wind, is not so controllable as the conventional power plant prime mover. However, it is interesting to note that the settling time has reverse trend at Po = 1 p.u.

I. INTRODUCTION

Over the years, motivated by the best pains of power engineers and electric utilities, there has been a considerable percentage of remotely located populations living without electrical power even to light up their lamps. The government helps and public functions are facing various limitations due to which the situation is not improving. One of the most important limitations being the locally existing cost-effective fuel capitals used for electricity generation. The energy in wind is existing profusely everywhere and the rapid development of technology in this area has motivated the engineers to harness the power from wind energy to provide the mandatory electrical power in these areas. The global electricity demand has been increasing due to fast and exponential growth in industrial development trends universally. There is a certain trend of increase in the comfort level of human beings which has added electric energy demand further. To keep track of increasing energy demands, power utilities have to put their best efforts to generate electrical power from the available renewable resources. The renewable energy sources also called non-conventional energy are environmentally outgoing and continuously replenished by natural processes. For example, solar energy, wind energy, bio-energy, hydropower, etc. A renewable energy system converts the energy found in these natural forms to a form that can be used as heat 2 or electricity. Most of the energy comes directly or indirectly from the sun and wind and can never be exhausted, and therefore are called renewable. Renewable energy resources may be used directly, such as solar ovens, geothermal heating, and windmills, etc., or indirectly by transforming to other more suitable forms of energy such as electricity age group through wind turbines or photovoltaic cells, or production of fuels from biomass like ethanol, etc. These developments have enabled the addition of 51 GW wind power capacity worldwide in 2014 to make 369.6 GW power from wind presented for use at the end of the year 2014, giving a growing rise of about 16%. Out of this, India has contributed 2,315 MW while China has continued the top spot again in 2014 by adding 23,196 MW capacity, followed by Germany with 5,279 MW, United States of America 3 with 4,854 MW, Brazil with 2,472 MW installed capacity. Fortunately, India is not lagging and has fifth place among the top ten wind power producers in the world and is the second-largest wind market in Asia after China. The developing trends in this area are encouraging and it is expected to be boosted extra

II. CUMULATIVE ACHIEVEMENTS OF RENEWABLE ENERGY IN INDIA

Continuous efforts are being made to reduce the capital cost mandatory to have power plants based on non-conventional and renewable sources of energy. At the same time, taking acceptable measures for the development of machinery and continuous growth of these sources. The efforts to increase the share of renewable in the total power generation capacity of India have yielded inspiring results. The growing achievements in India in renewable sources of energy are given in Table 1.1

Present achievement of power generation from renewable energy

Category	Achievement
SHS	150 MW
Solar Irrigation	1 MW
Roof top solar PV	14 MW
Wind Energy	2 MW
Biomass based electricity	<1 MW
Biogas based electricity	5 MW
Hydropower	230 MW
Total	403 MW

Source: (Halder et al, 2015)

A. Wind Energy

Wind energy is the kinetic energy connected with the undertaking of large masses of air. It is a clean, cheap, and eco-friendly renewable source and has disadvantages like it is dispersed, erratic, and setting specific source. The wind turbines arrest the kinetic energy in wind, and the generated electrical output varies due to the variable 14 nature of wind. Very slow winds are useless, having no possibility of power generation, whereas, very strong stormy winds cannot be employed due to the safety of the turbine. Moderate to high-speed winds, typically from 5m/s – 25m/s are considered favorable for most wind turbines. The global potential in winds for large-scale grid-connected power generation has been appraised as 9000 Tw / year (1T=1012). Its long-term technical potential is believed 5 times current global energy ingesting or 40 times current electricity demand. India has the 5th largest wind power fixed capacity of 24,376MW, in the world.

III. CONTROL TECHNOLOGY IN WIND POWER SYSTEM

A control scheme for variable speed wind energy conversion system (VSWECS) based on permanent magnet synchronous generator (PMSG) involving active and reactive power loops using simple tuning procedure of active damping is defined in. An inverter based on a new neutral-point-clamped pulse width modulation (PWM) technology has been developed for a wide-range variable-speed drive system to clamp the output terminal potential to the neutral point potential.

The uncoupling between active and reactive power and between torque and power factor can be empowered using a vector-controlled DFIG. Therefore, an optimal control strategy is planned to optimize the overall efficiency of the system. A 16 doubly-fed full controlled induction wind generator which offers high plasticity of stator side control to ensure nominal losses, as well as optimal power application, is investigated. Few notable donations have been cited by various researchers in the field. The nonlinearity of DFIG electrical dynamics is addressed using a nonlinear controller. The proposed approach is a combination of PI and Lyapunov-based auxiliary control, which stabilizes the internal dynamics and improves the DFIG post fault behavior through rotor control voltage. A brushless doubly-fed machine (BDFM) employs a wind-speed-estimation-based maximum power point tracker and a heuristic-model-based maximum efficiency point tracker to improve the power output of the system. An improved current control approach for brushless doubly-fed wind generation systems and utilizes the BDFM feature of independent speed and power control, enabling maximum power point tracking without any requirement of mechanical measurements or knowledge of machine parameters is conferred. An adaptive parameter estimation algorithm based on decoupled vector control modeling of DFIG is designed and by selecting a proper Lyapunov function, the parameters of DFIG can be estimated. An MPC controller is applied to a WECS connected to the utility grid. The optimal rectifier and inverter firing angle are calculated to regulate the DC link voltage for extracting maximum available wind power. The intelligent control systems are better than those of the current wind turbine control system. For turbulent wind, the intelligent control system smoothed the power output, generator torque, and rotor speed without compromising the electricity demand.

Various control strategies for wind power generation system are broadly classified as:

1) Traditional control method
2) Modern control method
3) Intelligent control method

IV. TRADITIONAL CONTROL METHOD

The conservative control strategy used in the wind power generation system is PID control, which is an easily understood algorithm that can provide excellent control performance. The majority of the wind turbines are installed with traditional Proportional–Integral (PI) algorithms.

The decoupled control of active and reactive power of a wind generator is achieved using a PI and a predictive-integral controller; while guaranteeing zero tracking error, fast response, and no exhibiting errors. The control of active power and reactive power of the wind turbine can be reached under two operating modes, i.e; maximum power tracking mode and power regulation mode. The maximum power tracking mode enables the wind turbine controller to capture the maximum wind energy to convert into electric energy, whereas the active power output is altered in power regulation mode to track the desired level.

The PI-controller limitations have to be adjusted according to change in a nonlinear device operating point, which is very difficult to achieve online. Moreover, PI structured controllers are slow and resulting in inactive system self-motivated response. The settling time of system response can be reduced by using high gain PI controllers but adding the cost of the controllers. PID control has a simple principle and its parameters setting are rather easy. However, they are not preferred for industrial applications due to problems connected with the derived part of the controller design.

V. MODERN CONTROL METHOD

A. *Optimal Control*

The synchronous generator is used for wind power generation in and a static excitations system is used. The transient steadiness signals derived from speed, terminal frequency, or power are superposed on the normal voltage signal of a voltage regulator, which provides additional damping to the oscillations. A wind turbine generator exhibits an unsteady input behaviour mainly because of unsteady wind speeds. This unsteady behaviour causes severe oscillations. The transient stability signals derived from the speed and terminal frequency are superposed on the normal voltage error signal of an automatic voltage regulator, thus providing damping to these oscillations. Also, the damping can be provided by using output feedback and the strip eigenvalue assignment technique. The eigenvalue's location affects the dynamics of the system. Therefore, it is necessary to locate the eigenvalues at some desired positions. The exact location of all eigenvalues at each operating point is difficult to attain. But a satisfactory response for both transient state and steady-state can be obtained by placing all eigenvalues within a suitable region in a complex s – plane.

B. *Suboptimal Control*

As associated with the outmoded single-input single-output (SISO) feedback control, an optimal control algorithm for a multi-input and multi-output (MIMO) wind turbine system enables more wind energy capture when the turbine operates in a narrow range of rotor velocity. A state observer is designed using the barrier Lyapunov function back-stepping procedure, in conjunction with an adaptive output feedback control for a class of nonlinear SISO systems to estimate the unmeasured states. Therefore, only one adjustable parameter needs to be updated, alleviating the online computation burden. The optimality of the wind power system about the trade-off between the wind energy conversion maximization and the minimization of the induction generator torque variation is achieved by using a combined optimization criterion, resulting in an LQ tracking problem with an infinite horizon and a measurable exogenous variable (wind speed). The proposed optimal controller and a proposed General Regression Neural Network controller are designed to drive the turbine speed to extract maximum power from the wind and adjust to the power regulation maintaining the system stability and reach the desired performance even with parameter uncertainties. A dynamic feedback controller can maximize the conversion efficiency and eliminate torque oscillations circulated through the drive train, which preserves the system structure and improve the system performance without measuring the wind velocity. The design of an adaptive output feedback controller for wind turbine generators using a neural network is proposed. The results obtained with output feedback controllers were compared with those reached with optimal controllers. However, only a set of variables has been used as feedback in the controller design.

VI. INTELLIGENT CONTROL TECHNIQUES

The classical control is very difficult to get, as it needs a truthful mathematical model. For a nonlinear system, the PID controller cannot provide a fast and accurate response. But the intelligent approach gives a better solution to the shortcomings of the PID controller, the pitch-control is carried out to pitch the rotor blades by the optimal amount to maximize the power output at all wind speeds.

The control process supported by data achievement arrangements and intelligent software (e.g., fuzzy-logic) helps in re-adjusting the control circuit for unexpected operating conditions. The control design based on the LQR of a wind-hybrid power system based on the Takagi– Sugeno fuzzy model is found to be more effective against disturbances caused by the wind speed and the load variations and better power quality is achieved. In this paper, an optimum fuzzy control adapts the rotational speed of the generator to the wind speed to extract maximum power.

The PI controller fails to provide sufficient damping during varying operating conditions. An adaptive conventional pitch controller based on artificial neural networks and fuzzy logic control algorithms is designed to capture the maximum wind power while reducing the mechanical loads.

1) *Step 1:* Fuzzification which involves conversion of real input variables into fuzzy linguist variables.
2) *Step 2:* Knowledge base fuzzy subset characterization by membership function. The membership functions used are triangular symmetric.
3) *Step 3:* Rule base comprising of fuzzy reasoning in the form of IF- THEN rules. The Mamdani implication is generally used for rule base.
4) *Step 4:* De-fuzzification is carried out to convert the fuzzy output variable to a crisp value for practical control implementation; for which centroid method is used.

VII. TYPES OF WIND TURBINE GENERATORS

There are various types of generators used for wind power generation; since wind, generation has started. They can be gathered into two major groups, the fixed speed turbine, and variable speed wind turbines.

The fixed speed configuration is considered by stiff power train dynamics because the electrical generator is locked to the grid, and therefore a small variation of the rotor shaft speed is allowed. The construction and performance of this type of system are very much dependent on the mechanical characteristic of the mechanical subsystems, pitch control time constant, etc. The most commonly used WTG, during the 1980s to 1990s, consists of a multiple-stage gearbox and a squirrel cage induction generator (SCIG) which is directly connected to the grid through a transformer. In this case, the generator directly couples the grid to drive the train. The SCIG were robust, inexpensive, and enable stall-regulated machines to operate at a constant speed leading to stable control frequency. This type of wind turbine is often operated off its optimum performance, and it generally does not extract the maximum power from the wind. The variable speed wind turbines (VSWT) use the high inertia of the rotating mechanical parts of the system as a flywheel; this helps to smooth power fluctuations and reduces the drive train mechanical stress. VSWT wind power generation system controls the blades to operate efficiently in a large range of rotating speed through changing the pitch angle, and this is a tendency in nowadays wind generation development. VSWT system includes synchronous generator system 4 and asynchronous generator system. The asynchronous generator usually consists of a stator holding a set of three-phase windings, which supplies the external load, and a rotor that provides a source of the magnetic field. The rotor may be supplied either from permanent magnetic or from a direct current flowing in a wound field. In a Wound Field Synchronous Generator, the stator winding is connected to the network through a four-quadrant power converter comprised of two back-to-back pulses with modulated[1]VSI converters. The stator side converter regulates the electromagnetic torque, while the supply side converter regulates the real and reactive power delivered by the WPS to the utility.

A. There are various types of generators used for wind power generation; since the wind generation has started.
B. They can be gathered into two major groups, the fixed speed turbine and variable speed wind turbines.
C. The fixed speed configuration is characterized by stiff power train dynamics due to the fact that electrical generator is locked to the grid; and therefore a small variation of the rotor shaft speed is allowed.
D. The construction and performance of this type of system are very much dependent on the mechanical characteristic of the mechanical subsystems, pitch control time constant, etc.

VIII. OPERATION AND CONTROL ASPECTS OF WTG

Wind turbine generators possess some special characteristics which are different from other types of generating units [21]. Many investigations on dynamic stability of wind turbine generators are reported in literature [22- 30]. One of the important aspects of the wind turbine generator is its effect on the stability of the system to which it is connected. However they are not responsible directly to the instability of the power systems [26- 27]. Power system stabilizers (PSS) have been employed to enhance the damping torque of wind turbine generators to reduce the impact. However, PSS designed considering a particular operating condition may not yield optimal performance when operating conditions change. This limitation was overcome by using adaptive control techniques.

The conventional control strategies used in the wind power generation system are PID structured control schemes. The schemes are simple and easy to understand and can provide good control performance. The majority of the wind turbines are 6 installed with traditional Proportional–Integral (PI) algorithms-based control systems. A classical PI controller and a predictive-integral controller are studied to achieve a decoupled control of the active and the reactive power injected into the grid by a wind generator. The controllers guarantee zero tracking error in steady state and the closed loop systems have shown the response when there are no modelling errors [31]. However, PI-controller parameters have to be adjusted according to change in a nonlinear device operating point, which is very difficult to achieve on-line. Moreover, PI structured controllers are slow and resulting in sluggish system dynamic response. The settling time of system response can be reduced by using high gain PI controllers [32]. PID control has simple principle and its parameter setting is easy.

IX. SENSITIVITY ANALYSIS

A. Generally, sensitivity index is used to analyze the system dynamic behavior when subjected to a change.
B. This helps to design the appropriate control scheme for the system which can accommodate the effect of these changes.
C. For wind energy generating systems, various parameters are used to model the system which includes wind speed, rotor angle, field voltage, direct and quadrature axis reactance of rotor, line reactance etc.
D. Generally, these system parameters are treated as constant while developing the system dynamic model.

E. However, the system parameters vary due to system operating conditions, ageing of the mechanical parts of the system and environmental conditions [46].
F. Greater the sensitivity, less desirable is the change in parameters.
G. It is necessary to identify the sensitive parameters and the extent to their variations which they affect the system performance.

X. OBJECTIVES OF THE THESIS

The objectives of this thesis are set forth as

1) To develop mathematical model of an isolated WTG model connected to an infinite bus through a transmission link.
2) To design optimal controllers for the WTG and analyzing the simulated results obtained with and without designed optimal controller.
3) To design suboptimal controllers for the WTG system and analyse the system dynamic performance obtained with the implementation of designed suboptimal controller, and comparing the results with that obtained with optimal controller.
4) To design conventional PID controllers for the WTG. The simulation study is to be carried out with the implementation of designed PID controller.
5) To design the intelligent FLC controller for the WTG; and analyzing the system dynamic performance with both PID and FLC controllers.
6) To test the feasibility of the designed controllers for the WTG with the implementation of these controllers.

A. Limitations

1) The Wind has limited speed which lessened the resultant kinetic energy of the wind energy.
2) The speed of the wind is not constant.
3) Production of wind energy is a long-term process i.e. it requires a long time to get a significant amount of energy.

B. Advantages

1) Wind creates jobs.
2) Wind enables U.S. industry growth and U.S. competitiveness.
3) Wind power is cost-effective.
4) It's a clean fuel source.
5) Wind is a domestic source of energy.
6) It's sustainable.
7) Wind turbines can be built on existing farms or ranches.

C. Disadvantages

1) The wind is inconsistent.
2) Wind turbines involve high upfront capital investment.
3) Wind turbines have a visual impact.
4) May reduce the local bird population.
5) Wind turbines are prone to noise disturbances.
6) Installation can take up a significant portion of land.
7) Wind turbines can be a safety hazard.

XI. CONCLUSION

Every wind turbine lasts for about 20-25 years. As long as the wind blows, wind turbines can harness the wind to create power. Wind power only makes up a tiny percent of electricity that is produced. Unlike coal, wind turbines don't create greenhouse gases and are completely renewable source.

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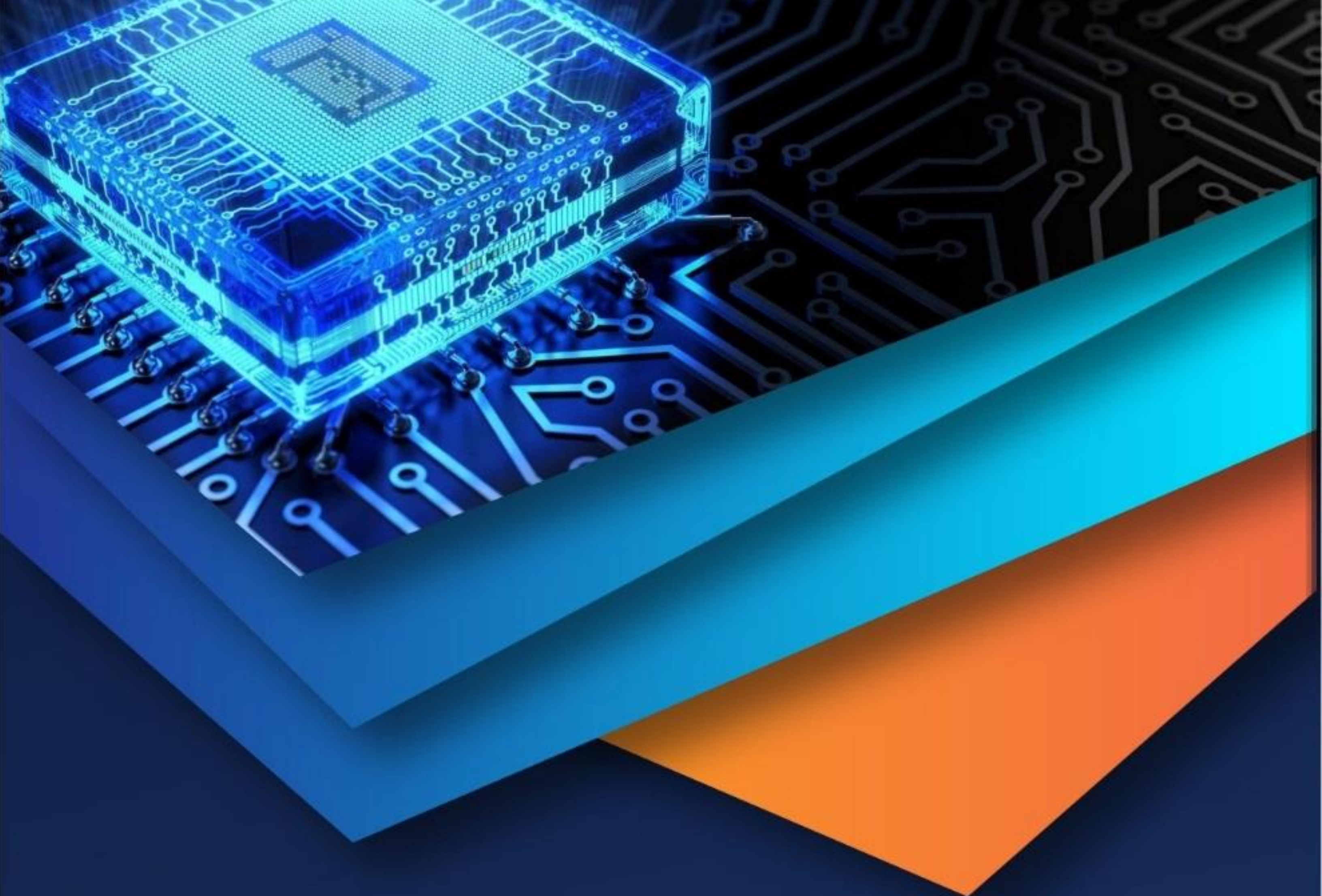

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