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EVALUATING THE PERFORMANCE OF POWER POINT TRACKING FOR WIND TURBINE USING UNIFIED GENERATOR–RECTIFIER APPROACHES

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ABSTRACT

Maximizing energy capture from wind turbines is critical for enhancing the efficiency and reliability of wind power generation systems. A key technique to achieve this is through Maximum Power Point Tracking (MPPT), which ensures the turbine operates at its optimal power point under varying wind conditions. This paper investigates the performance of MPPT for wind turbines using unified generator–rectifier approaches, which integrate the control of both the generator and rectifier stages to optimize energy conversion. The unified generator–rectifier approach enables coordinated control between the turbine's mechanical dynamics and the electrical system, enhancing MPPT efficiency. By analyzing various control strategies, including direct torque control (DTC), field-oriented control (FOC), Comparative analysis shows that the unified approach offers better overall system efficiency and smoother operation compared to traditional decoupled control methods. The results confirm that integrating generator and rectifier control not only improves MPPT accuracy but also reduces power losses and enhances the dynamic performance of the wind turbine system, particularly in fluctuating wind environments. This research highlights the importance of MPPT in wind turbines and introduces the unified generator–rectifier approach as a means to improve energy conversion efficiency. It also touches on the techniques used and the results of their evaluation.

Keywords: *Maximum Power Point Tracking (MPPT), Wind Turbine Control, Energy Conversion Efficiency, Unified Generator–Rectifier Approach, Power Optimization.*

INTRODUCTION:

The global demand for renewable energy sources, particularly wind energy, has driven significant advancements in wind turbine technology. One of the primary challenges in wind energy systems is ensuring optimal power extraction across a wide range of wind conditions. Wind turbines operate most efficiently when they are able to track and maintain their Maximum Power Point (MPP), which corresponds to the optimal combination of rotor speed and wind velocity that maximizes energy conversion [1]. To achieve this, Maximum Power Point Tracking (MPPT) algorithms are implemented to dynamically adjust the turbine's operating parameters. Traditional MPPT approaches have typically employed separate control mechanisms for the generator and the rectifier, treating them as distinct components in the energy conversion chain. However, this decoupled control strategy can result in inefficiencies, particularly under fluctuating wind conditions where rapid adjustments are required. A unified generator–rectifier approach offers a promising solution by coordinating the control of both the generator and rectifier stages to optimize overall system performance [2]. This paper aims to evaluate the performance of MPPT using a unified generator–rectifier control strategy for wind turbines. The unified approach allows for seamless interaction between the mechanical and electrical subsystems of the turbine, ensuring more accurate power point tracking, reducing energy losses, and enhancing system responsiveness. Through comparative analysis of control techniques such as Direct Torque Control (DTC), Field-Oriented Control (FOC), and advanced algorithms like fuzzy logic and neural networks, the study assesses the potential improvements in energy capture and system stability. By integrating the control of both the generator and rectifier, this research highlights the advantages of the unified approach in increasing energy conversion efficiency and maximizing the potential of wind turbine systems, even in the face of unpredictable wind conditions. This Research provides a clear overview of the need for efficient MPPT in wind turbines, the limitations of traditional approaches, and the promise of a unified generator–rectifier strategy for improving system performance [3]. Wind turbine power-point tracking architecture: the prime mover is a variable-speed wind turbine. The turbine shares a common shaft with the multiport PMSG. AC power is converted to dc by an integrated generator–rectifier system. The dc output is connected to a stiff dc interface. The integrated generator–rectifier system performs maximum power-point tracking to extract the turbine maximum power. (b)

Each phase of a three-phase ac port is modeled by a back EMF source in series with generator inductance L and phase resistance R. The passive rectifier is a six-pulse diode rectifier, and the active rectifier is a three-phase two-level converter [4].

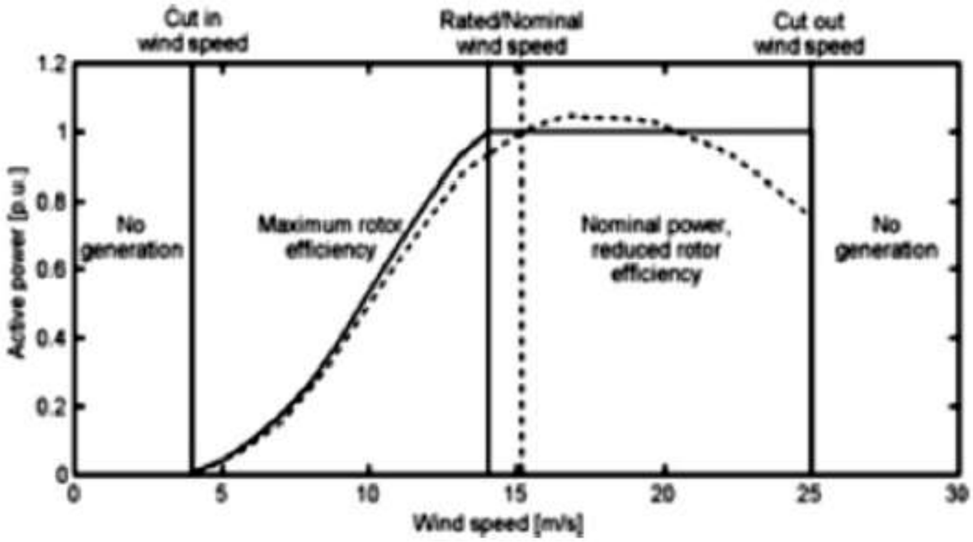

Figure1: Characteristics power curve of controlled wind turbine.

LITERATURE SERVEY

Harvesting offshore energy requires multimegawatt wind turbines and high efficiency, high power density, and reliable power conversion systems to achieve a competitive levelized cost of electricity. An integrated system utilizing one active and multiple passive rectifiers with a multiport permanent magnet synchronous generator is a promising alternative for an electromechanical power conversion system. Deployment of the integrated systems in offshore wind energy requires maximum power point tracking (MPPT) capability, which is challenging due to the presence of numerous uncontrolled passive rectifiers [5]. This article shows feasibility of MPPT based on a finding that the active-rectifier d-axis current can control the total system output power. The MPPT capability opens up opportunities for the integrated systems in offshore wind applications. wind supply chain globally, but also great opportunities, for Norway as well as other countries. It also shows that we have a way to go preparing a supply chain for serial manufacturing of floating offshore wind. In a Norwegian context, we need a discussion on how our supply industry can capitalize on the need for more industry capacity in offshore wind, especially floating. says Jon Evang, director Offshore Wind in Renewables Norway [6]. This paper describes the design of a rotor and a wind turbine for an artificial 10-MW wind turbine carried out in the Light Rotor project. The turbine called the Light Rotor 10-MW Reference Wind Turbine (LR10- MW RWT), is designed with existing methods and techniques and serves as a reference to future advanced rotor designs in the project. The results shown in this paper are not for the final design, but for Iteration #2 in the design process. Several issues in the design process were highlighted [7]. Before carrying out the design many decisions have to be made and this paper elaborate on issues like the determination of the specific power and upscaling of the turbine. The design of Iteration #2 of the LR10-MW RWT is carried out in a sequence between aerodynamic rotor design, structural design and aero-servo-elastic design. Each of these topics is described. The results from the Iteration #2 design show a rather well performing wind turbine both in terms of power and loads, but in the further work towards the final design the challenges in the control needs to be solved and the balance between power performance and loads and between structural performance and mass will be investigated further resulting in changes in the present design [8].

METHODOLOGY:

GRID-connected wind electricity generation shows the highest rate of growth of any form of electricity generation, achieving global annual growth rates in the order of 20 - 25%. It is doubtful whether any other energy technology is growing, or has grown, at such a rate. Wind power is increasingly being viewed as a mainstream electricity supply technology. Its attraction as an electricity supply source has fostered ambitious targets for wind power in many countries around the world.

WIND SYSTEM

GRID-connected wind electricity generation shows the highest rate of growth of any form of electricity generation, achieving global annual growth rates in the order of 20 - 25%. It is doubtful whether any other energy technology is growing, or has grown, at such a rate. Global installed capacity was 47.6 GW in the year 2004 and 58.9 GW in 2005. Wind power is increasingly being viewed as a mainstream electricity supply technology. Its attraction as an electricity supply source has fostered ambitious targets for wind power in many countries around the world. Wind power penetration levels have increased in electricity supply systems in a few countries in recent years; so have concerns about how to incorporate this significant amount of intermittent, uncontrolled and non-dispatchable generation without disrupting the finely-tuned balance that network systems demand. Grid integration issues are a challenge to the expansion of wind power in some countries. Measures such as aggregation of wind turbines, load and wind forecasting and simulation studies are expected to facilitate larger grid penetration of wind power.

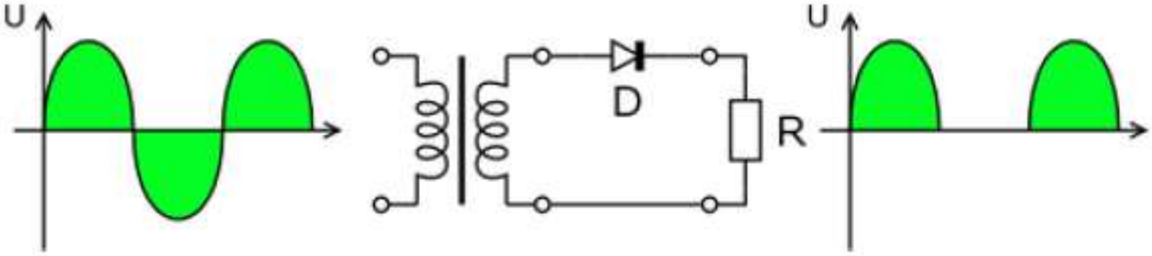

Figure2: Half-Wave Rectifier

In half wave rectification, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, it is very inefficient if used for power transfer. Half-wave rectification can be achieved with a single diode in a one-phase supply, or with three diodes in a three-phase supply

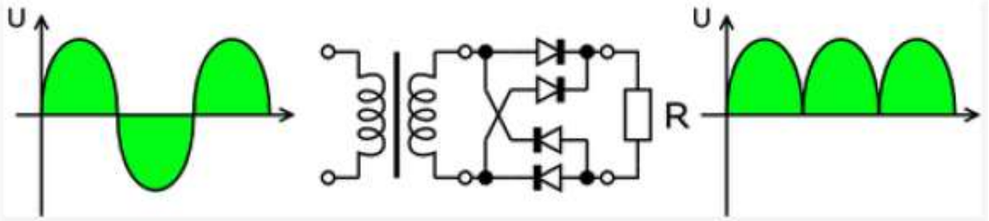

Figure3: Full-Wave Rectifier

A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Full-wave rectification converts both polarities of the input waveform to DC (direct current), and is more efficient. However, in a circuit with a non-center tapped transformer, four diodes are required instead of the one needed for half-wave rectification. Four diodes arranged this way are called a diode bridge or bridge rectifier

Rectification Technology

Early power conversion systems were purely electro-mechanical in design, since electronic devices were not available to handle significant power. Mechanical rectification systems usually rely on some form of rotation or resonant vibration in order to move quickly enough to match the frequency of the input power source, and cannot operate beyond several thousand cycles per second. To convert AC currents into DC current in electric locomotives, a synchronous rectifier may be used. It consists of a synchronous motor driving a set of heavy-duty electrical contacts. The motor spins in time with the AC frequency and periodically reverses the connections to the load just when the sinusoidal current goes through a zero-crossing. The contacts do not have to switch a large current, but they need to be able to carry a large current to supply the locomotive's DC traction motors. There is an interesting equivalence between the various parameters describing electrical and mechanical forms of energy. People with either electrical or mechanical backgrounds find this equivalence useful to the understanding of the physical process in either form of energy. The magnitude of the voltage induced in the stator winding is, as shown above, a function of the magnetic field intensity, the rotating speed of the rotor, and the number of turns in the stator winding. An actual description of individual coil design and construction, as well as how the completed winding is distributed around the stator, is meticulously described in Chapter 2. In this section a very elementary description of the winding arrangement is presented to facilitate the understanding of the basic operation of the machine. As stated above, coils are distributed in the stator in several forms. Each has its own advantages and disadvantages. There are three main types of wind turbines currently in use: the fixed speed wind turbine with Squirrel Cage Induction Generator (IG), the variable speed wind turbine with Doubly Fed Induction Generator (DFIG), and the variable speed wind turbine with Permanent Magnet Synchronous Generator (PMSG). A brief distinction of the 3 types of wind turbine driven generators is given below.

RESULT ANALYSIS:

The basic goal is to obtain three balanced and sinusoidal voltages having very little harmonic content (harmonic voltages and currents are detrimental to the machine and other equipment in several ways). To achieve a desired voltage and MVA rating, the designer may vary the number of slots, and the way individual coils are connected, producing different winding patterns. the simulation model including the power electronics switching events for verifying the relationship between the d-axis current and the dc-bus power, as in (6). A three-port PMSG is modeled by three voltage sources in series with resistance and inductance. The frequency and amplitude of the voltage sources are dependent on an external reference-speed signal. Parameters of each port follow the values given in Section II-B. Port-1 and -2 are connected to three-phase diode rectifiers. The phase-A voltages (and also Phase-B and -C) of these two ports are shifted by π 6 electrical radian from each other to minimize the voltage ripple on the passive rectifiers' dc output. Port-3 powers an insulated-gate bipolar transistor (IGBT)-based active rectifier that switches at 2 kHz. The rectifier outputs are serially connected to form the dc bus. The dc-bus voltage is maintained at 5.7 kV to represent the grid interface.

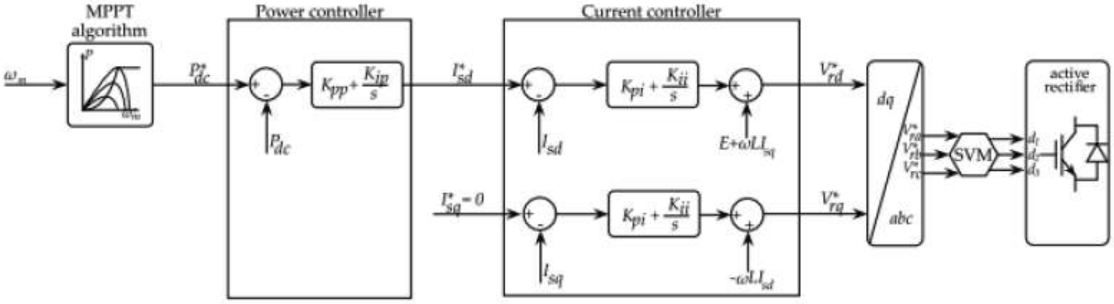

Figure4: The design of power-flow control for the absolute unified generator–rectifier

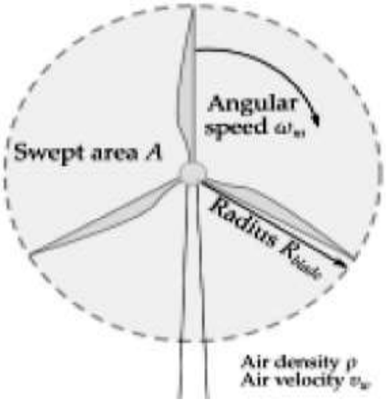

Figure5: Demonstration of a three-bladed wind turbine

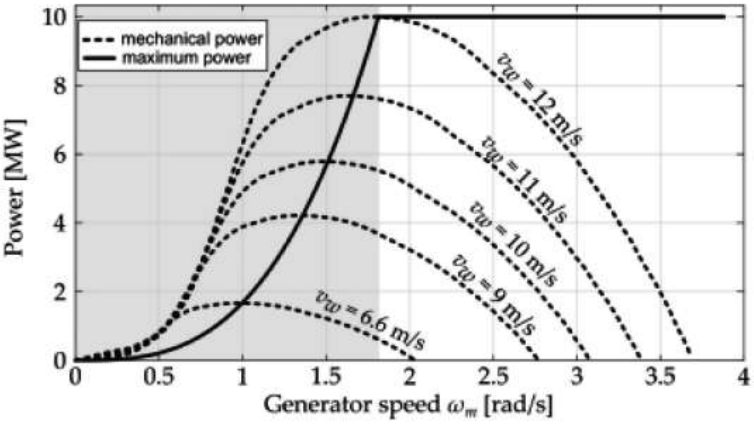

Figure6: Demonstration of maximum power curve of wind turbine

CONCLUSION:

This study demonstrates that the unified generator–rectifier approach significantly improves the performance of Maximum Power Point Tracking (MPPT) for wind turbines, offering enhanced energy conversion efficiency and better dynamic response to changing wind conditions. By integrating the control of the generator and rectifier stages, this approach ensures more precise and coordinated operation, addressing the limitations of conventional decoupled control methods. The evaluation of various control strategies—such as Direct Torque Control (DTC), Field-Oriented Control (FOC), and intelligent algorithms like fuzzy logic and neural networks—reveals that the unified control system enables faster and more accurate tracking of the Maximum Power Point (MPP). This results in increased energy capture, reduced power losses, and improved system stability across a wide range of wind speeds. Moreover, the unified approach demonstrated smoother transitions and superior overall performance, particularly in fluctuating wind environments, compared to traditional methods. The unified generator–rectifier approach is a promising solution for maximizing the efficiency and reliability of wind turbines. The integration of both mechanical and electrical control strategies opens new opportunities for further optimization and adaptation to the evolving demands of renewable energy systems. Future research may focus on refining these control techniques to make wind energy systems even more robust and adaptable to varying environmental conditions.

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