TRACKING THE MAXIMUM AMOUNT OF POWER GENERATED BY HYBRID SOLAR-WIND RENEWABLE ENERGY GENERATORS WITH THE USE OF MACHINE LEARNING TECHNIQUES

K.SAI HARSHA SREE[1], D. MANIKANTA[2], D. PRASHANTH[3], V. HEMAPRIYA[4], U. SANDEEP[5], CH. PRASANNA[6]

UG SCHOLAR[1,2,3,4&5], DEPARTMENT OF EEE, NARSIMHA REDDY ENGINEERING COLLEGE (UGC-AUTONOMOUS), MAISAMMAGUDA (V), KOMPALLY, SECUNDERABAD, TELANGANA-500100

ASSISTANT PROFESSOR[6], DEPARTMENT OF EEE, NARSIMHA REDDY ENGINEERING COLLEGE (UGC-AUTONOMOUS), MAISAMMAGUDA (V), KOMPALLY, SECUNDERABAD.

ABSTRACT

In this paper, a neural network tuned controller for maximum power point tracking (MPPT) in wind energy conversion system (WECS) is proposed. This technique utilizes radial basis function based neural networks (RBF-NN) and tracks the MPP using duty cycle control. The WECS is based on permanent magnet synchronous generator (PMSG). The rectifier output voltage and power are measured and fed into an RBF-NN controller. The MPPT algorithm controls the duty cycle of a DC-DC boost converter to extract the maximum power. The output of the boost converter is tied to the grid using a voltage source inverter (VSI). Unlike conventional methods, MPPT using proposed method does not require knowledge of wind turbine power characteristics, thus minimizes the need for various measuring instruments. The method implemented is also compared with other commonly used MPPT techniques like fuzzy logic control (FLC), perturb & observe (P&O), and back-propagation (BP) based NN. The proposed system provides better results as compared with other relevant results available in the literature. The proposed method is implemented using MATLAB/Simulink and then validated in real-time using digital simulation hardware, OPAL-RT 4510.

1.INTRODUCTION

Due to increasing global warming, pollution and fossil fuel exhaustion renewable energy sources are being used increasingly nowadays. Wind power is reliable and quick developing among various renewable energy sources. Wind energy has gained importance as a renewable and green energy resource in the last few years [1]. In a WECS, kinetic energy of the wind is converted to mechanical energy of the rotor, which is then converted to electrical energy through the permanent magnet synchronous generator (PMSG) [2]. The PMSG based WECS is used in this work, as it has multiple advantages like, lower excitation losses, better efficiency, higher power density, better grid support capacity and much lower maintenance cost as compared to other types. PMSG also has the advantage of no field losses and high frequency regulation in addition to smaller blade diameter [3], [4], [5], [6]. As the wind speed varies, the power output varies thus it is mandatory to track the maximum power output from a WECS. Wind turbines are mainly of fixed and variable speed type. Variable speed wind turbines have better quality and more control over output power [7], [8], [9].These turbines can be used to track MPP for various wind speeds by varying the rotor speed to keep the power coefficient (C_p) maximum at all times. Pitch angle control can further be implemented in these wind turbines to achieve maximum power at speeds above rated wind speed. These wind turbines have higher starting torque, more stable and flatter torque curves. They are also more resilient to turbulent wind speeds and give low mechanical stress [10]. Ample research is being carried out to tap the maximum power from wind energy [11]. Some of the more common methods used to implement MPPT are tip-speed ratio (TSR) control, P&O, optimal torque (OT) control and power signal feedback (PSF) methods [12]. In case of TSR control, the rotor speed is adjusted to get the optimum TSR for each wind speed to obtain maximum power. In this control, the wind and the rotor speeds need to be measured, which increases the cost as the anemometers and tachometers required to measure those speeds, are expensive. In P&O method, maximum power is obtained in much iteration, which makes this method ineffective for rapidly varying wind speeds. However, it has an advantage of not requiring the turbine power characteristics or the wind speed knowledge. In PSF method, the knowledge about wind turbine maximum power curves is essential [13], [14], [15], [16], [17], [18]. The conventional strategy like P&O, TSR, and OT etc. perform poorly during varying wind speeds and require precise mathematical models. These conventional controllers have problems of inefficient tuning of their gains therefore intelligent controllers are used to overcome this problem and for better system performance. The usage of artificial intelligence (AI) based control methods minimizes some of these issues and play a significant role in extracting MPP [19], [20]. The AI approaches such as neural network and fuzzy system do not require mathematical models and are capable of approximating nonlinear systems. As a result, many researchers have used these to depict complex plants and build sophisticated controllers. The FLC based MPPT was applied to control the boost converter to achieve maximum efficiency for small scale WECS due to its fast convergence [21], [22]. Li et al. [23] presented the BP-NN based MPPT to extract maximum power with higher efficiency, reliability and without using mechanical sensor. Based on the power slope versus the wind turbine rotation speed, this study proposes a novel MPPT algorithm employing AI based techniques to avoid the effect of oscillation and uncertain parameters in wind turbine generators. The output voltage and current characteristics of the wind turbine generator are determined by the amount of wind speed. The ambient air density and the electrical load characteristics are required to implement MPPT algorithms to ensure that wind turbine generators achieve optimum efficiency under different operating conditions. Being powerful for mapping a function, NN are used in many fields, such as prediction of wind and power. To enhance MPPT's efficiency, a novel controller using the RBF-NN based adaptive strategy is proposed here for WECS. The proposed RBF-NN approach optimizes the duty cycle to extract MPP. The RBF-NN is a feedforward NN with a much simpler structure than BP-NN. It provides a robust and adaptive control system. In addition, the boost converter duty cycle is controlled using voltage and power as inputs to the NN, the need of knowing the wind turbine characteristics is eliminated. Thus, it does not need sensors to measure the wind speed (anemometer) or to measure the turbine speed (tachometer) which makes this MPPT control technique much more cost-efficient. This control strategy provides efficient MPPT, reduces ripples, minimizes load variations& discontinuities and yields fast response. This method is also compared with P&O, FLC and BP-NN to check its performance. A double stage grid interfaced WECS topology is designed, modeled and implemented in this paper. In first stage, the WECS is implemented as a standalone system in which a load is connected at the output of the boost converter. In the second stage, the WECS is tied to a grid. The major contributions of this work are as follows:

2.LITERATURE SURVEY

S. Li et al. A RBF neural network based MPPT method for variable wind speed turbine

Wind turbine system due to its aerodynamic and generator components is a nonlinear and strongly coupled system. These characteristics influence the efficiency and performance of the systems output. In order to improve the efficiency of Maximum Power Point Tracking (MPPT) and to produce more green energy, a novel control strategy which is based on RBF neural network is designed. The proposed algorithm depends on the optimal tip speed ratio and adjusts rapidly the output of torque with the random wind. Finally, to validate and demonstrate the performance of the proposed method, the FAST and Matlab/Simulink are used to test under different conditions of Wind. Due to increasing global warming, pollution and fossil fuel exhaustion renewable energy sources are being used increasingly nowadays. Wind power is reliable and quick developing among various renewable energy sources. Wind energy has gained importance as a renewable and green energy resource in the last few years [1]. In a WECS, kinetic energy of the wind is converted to mechanical energy of the rotor, which is then converted to electrical energy through the permanent magnet synchronous generator (PMSG) [2]. The PMSG based WECS is used in this work, as it has multiple advantages like, lower excitation losses, better efficiency, higher power density, better grid support capacity and much lower maintenance cost as compared to other types. PMSG also has the advantage of no field losses and high frequency regulation in addition to smaller blade diameter [3], [4], [5], [6].

A. Dahbi et al. A novel combined MPPT-pitch angle control for wide range variable speed wind turbine based on neural network Int J Hydrogen Energy (2016)

The objective of this paper is to develop a novel combined MPPT-pitch angle robust control system of a variable-speed wind turbine. The direct driven wind turbine using the permanent magnet synchronous generator (PMSG) is connected to the grid by means of fully controlled frequency converters, which consist of a pulse width-modulation PWM rectifier connected to an inverter via an intermediate DC bus. In order to maximize the exploited wind power and benefit from a wide range of the wind speed, a novel combined maximum power point tracking (MPPT)-Pitch angle control is developed using only one low cost circuit based on Neural Network (ANN), which allows the PMSG to operate at an optimal speed to extract maximum power when this last is lower than nominal power, and limit the extra power. To achieve feeding the grid with high-power and good quality of electrical energy, the inverter is controlled by (PWM) in a way to deliver only the active power into the grid, and thus to obtain a unit power factor. DC-link voltage is also controlled by the inverter. The dynamic and steady-state performances of the wind energy conversion system (WECS) are carried by using Matlab Simulink. The needs increasing of energy and the harmful impact on the environment caused by fossil fuels (such as pollution, acid rain and the greenhouse effect) made renewable energies a very important solution. Among these renewable sources we find the wind energy.

W. Lin et al. Hybrid intelligent control of PMSG wind generation system using pitch angle control with RBFN Energy Convers Manage (2011)

This paper presents the design of a fuzzy sliding mode loss-minimization control for the speed of a permanent magnet synchronous generator (PMSG) and a high-performance on-line training radial basis function network (RBFN) for the turbine pitch angle control. The back-propagation learning algorithm is used to regulate the RBFN controller. The PMSG speed uses maximum power point tracking below the rated speed, which corresponds to low and high wind speed, and the maximum energy can be captured from the wind. A sliding mode controller with an integral-operation switching surface is designed, in which a fuzzy inference mechanism is utilized to estimate the upper bound of uncertainties. Furthermore, the fuzzy inference mechanism with center adaptation is investigated to estimate the optimal bound of uncertainties. Recently, wind generation systems are attracting great attentions as clean and safe renewable power sources. Wind generation can be operated by constant speed and variable-speed operations using power electronic converters. The variable-speed generation system is more attractive than the fixed-speed system because of the improvement in wind energy production and the reduction of the flicker problem. And the wind turbine can be operated at the maximum power operating point for various wind speeds by adjusting the shaft speed optimally to achieve maximum efficiency at all wind velocities [1], [2]. All these characteristics are advantages of the variable-speed wind energy conversion systems (WECS). In order to achieve the maximum power control, some control schemes have been studied.

M. Elnaggar et al. Maximum power tracking in WECS (Wind energy conversion systems) via numerical and stochastic approaches Energy (2014)

This paper presents a complete design of a two-level control system to capture maximum power in wind energy conversion systems. The upper level of the proposed control system adopts a modified line search optimization algorithm to determine a setpoint for the wind turbine speed. The calculated speed setpoint corresponds to the maximum power point at given operating conditions. The speed setpoint is fed to a generalized predictive controller at the lower level of the control system. A different formulation, that treats the aerodynamic torque as a disturbance, is postulated to derive the control law. The objective is to accurately track the setpoint while keeping the control action free from unacceptably fast or frequent variations. Simulation results based on a realistic model of a 1.5 MW wind turbine confirm the superiority of the proposed control scheme to the conventional ones. Wind energy is one of the fast-growing renewable energy resources [1], [2], [3], [4], [5]. WECS (Wind energy conversion systems) may implement either fixed speed wind turbines or VSWT (variable-speed wind turbines). The current trend is to use VSWT. VSWT allow different control schemes to maximize the captured energy, attenuate the mechanical stresses, and improve the generated power quality [1]. Our objective in this work is to achieve MPPT (maximum power point tracking) for VSWT and, consequently, improve the efficiency of WECS.

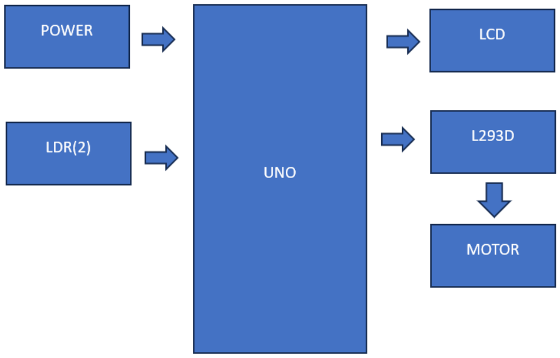
Depending on the wind speed, VSWT have generally two main regions of operation as shown in Fig. 1. The first region is the partial load regime. It extends from the cut-in wind speed to the rated wind speed of a specific wind turbine. The task of the control system in this region is to achieve MPPT. The second region is the full load regime. It extends from the rated wind speed to the cut-out wind speed of the turbine. The task of the control system in this region is to regulate the turbine speed and power at their rated values using collective pitch control [6]. Individual pitch control can also be used to reduce the mechanical stresses. Here, our focus is on MPPT in the first region.

M.A. Abdullah et al. A review of maximum power point tracking algorithms for wind energy systems Renew Sustain Energy Rev (2012)

Renewable energy resources are gaining a lot of popularity. Several researchers have worked on the tracking and extraction of energy from these sources. In the past few decades, among the available green energy resources, wind energy has been the most attractive option among the resources available. It is imperative to use the maximum power available in the wind to achieve the wind turbine (WT) operation at maximum power. The maximum power point tracking (MPPT) algorithms are a pioneer in this context. Many research papers are contributed in this domain which necessitates a thorough review while choosing an appropriate technique. This paper comprehensively focuses on reviewing different algorithms in the past and present for tracking maximum power point, and capturing maximized output power from the wind energy conversion system (WECS). In this paper, the algorithms are classified based on the direct and indirect power measurement, hybrid and smart algorithms for tracking maximum power point, and they are compared, considering the parameters like complexity, convergence speed, use of sensors, memory requirement, need for knowledge of system parameters, etc. The immense popularity of the different versions of perturb and observe (P&O) based algorithms due to their various features is evident from the literature. The review reveals that the hybrid maximum power point tracking algorithms can use the advantages of the conventional methods and eliminate their drawbacks. With the ever-increasing prices, the increasing need for conventional fuels, and the decline in their availability, renewable energy resources such as wind energy are gaining immense popularity. Moreover, it is a form of green energy that is environment friendly. Globally, a remarkable increase is observed in the installation of wind power plants consistently [1,2] as depicted in Figure 1. By the year 2022, the global installed wind capacity will reach 840 GW. The basic nature of wind being extremely fluctuating, the optimal speed of the generator has to be maintained to obtain maximum yield of energy from WECS. Therefore, tracking the MPP is very popular and extremely important for ensuring the maximum capture of energy from the WECS for different varying speeds of the wind. As portrayed the kinetic energy present in the wind serves as an input to the WECS. The output of the WECS becomes fluctuating as the continuous changes in the speed of the wind influence it. The most important function of a WT is to provide mechanical energy by transforming the kinetic energy present in the wind, which can then drive the generator to produce clean electrical energy. Maximum energy extraction is possible for all variable speeds of the wind as the wind turbine with variable speed has a speed shaft that is adjustable [4,5].

3.IMPLEMENTATION

BLOCK DIAGRAM



BLOCK DIAGRAM DESCRIPTION

REGULATED POWER SUPPLY:

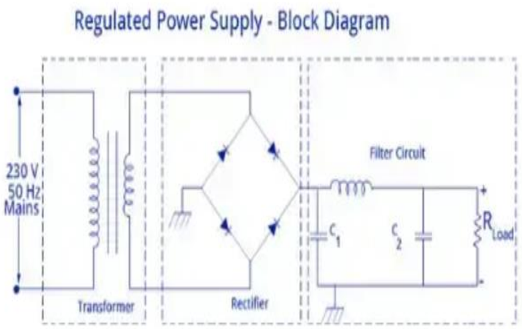


Fig: Regulated Power Supply Diagram

A regulated power supply provides a stable DC output by transforming variable AC input.

Component Overview: The essential components of a regulated power supply consist of a transformer, rectifier, filter, and regulator, each vital for ensuring a stable DC output.

The rectification process involves diodes transforming alternating current (AC) into direct current (DC), sometimes using full-wave rectification to optimize efficiency.

Filter Function: Filters, including capacitor and LC kinds, mitigate ripple and stabilize the DC output voltage.

Regulatory Mechanism: Regulators modulate and stabilize output voltage to safeguard against input fluctuations or load variations, crucial for a dependable power supply.

MICRO CONTROLLER

ARDUINO

The Arduino is a series of microcontroller boards designed to facilitate electrical design, prototyping, and experimentation for artists, hackers, amateurs, and even professionals. Individuals use it as the cognitive component for their robots, to create innovative digital musical instruments, or to develop a system that enables houseplants to notify you via Twitter when they want water. Arduino boards, namely the basic Arduino Uno, are constructed around an ATmega microcontroller, which functions as a comprehensive computing unit including a CPU, RAM, Flash memory, and input/output ports, all integrated into a single chip. In contrast to a Raspberry Pi, it is designed to connect various sensors, LEDs, tiny motors, speakers, servos, and similar components directly to these pins, which may read or output digital or analog voltages ranging from 0 to 5 volts. The Arduino interfaces with your computer by USB, allowing you to program it in a straightforward language (C/C++, akin to Java) using the complimentary Arduino IDE by uploading your developed code to the board. Once programmed, the Arduino may operate via a USB connection to your computer or independently without it—requiring just a power source, devoid of a keyboard or display

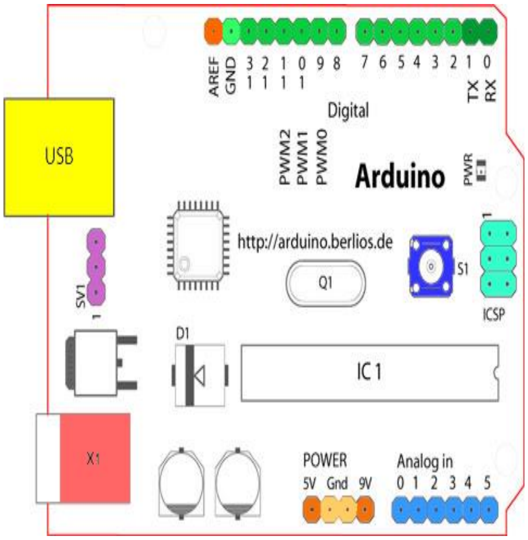


Fig: Structure of Arduino Board

SENSOR

A sensor is a device that identifies and reacts to certain stimuli from the physical world. The input may consist of light, heat, motion, moisture, pressure, or several other environmental phenomena. The output is often a signal that is either translated to a human-readable format at the sensor site or transferred electronically via a network for interpretation or further processing.

LDR

A photo resistor or Light Dependent Resistor or CdS Cell is a resistor whose resistance decreases with increasing incident light intensity. It can also be referred to as a photoconductor. A photo resistor is made of a high resistance semiconductor. If light falling on the device is of high enough frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electron (and its hole partner) conduct electricity, thereby lowering resistance.

CONCLUSION

The standalone hybrid solar-wind renewable energy system with maximum power extraction based on PSO has been described in this article. The HRES consists of a 2.5kW PV system and an 8.5 kW PMSG wind turbine with duty cycle settings on the boost converter to obtain MPP from both sources. According to the simulation results, the hybrid system produces power of 1071 Watt and 6642 Watt respectively at 600 W/m2 irradiation and 10m/s2 wind speed. When given changes in wind and solar irradiation, maximum power extraction with PSO can track the maximum power following these changes. The DC bus voltage can be maintained constant at 450V through inverter control despite changes in wind speed and solar irradiation. Compared to the P&O algorithm, the PSO produces more power and less oscillations so that it has better performance. Future work this algorithm will be developed to implement on the prototype of small-scale solar wind renewable energy system in off-grid application.

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