Integrating Wind and Solar Energy: Performance Evaluation of Hybrid Systems with Advanced Control

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Abstract–This study focuses on the integration of wind and solar energy sources to create hybrid power systems, with an emphasis on evaluating their performance through advanced control techniques. The increasing demand for sustainable energy solutions has driven the need for efficient utilization of renewable resources. Wind and solar energies, being prominent among these resources, offer substantial potential for power generation.

The paper investigates the performance of hybrid systems that combine both wind and solar energy generation. These systems are designed to seamlessly switch between the two sources based on availability and prevailing environmental conditions. The integration is facilitated by advanced control mechanisms that ensure optimal power capture and distribution.

The evaluation encompasses various aspects of performance, including efficiency, reliability, and grid adaptability. The hybrid system's ability to handle fluctuating conditions and its response to grid perturbations are studied comprehensively. Furthermore, the influence of different control strategies on overall system performance is analyzed.

In addition to technical performance, the economic feasibility of these hybrid systems is also considered. The cost-effectiveness of integrating wind and solar energy is assessed, taking into account factors such as initial setup costs, maintenance, and potential energy savings over time.

The study employs simulations and data analysis to quantify the advantages and challenges associated with integrating wind and solar energy. Results are presented that highlight the benefits of advanced control in enhancing energy capture efficiency and system stability. Furthermore, insights into the potential environmental and economic benefits of such hybrid systems are discussed.

In conclusion, this paper contributes to the ongoing efforts to develop sustainable energy solutions by presenting a comprehensive performance evaluation of hybrid wind and solar power systems. The integration of advanced control techniques adds a layer of sophistication to the system's functionality, making it a promising avenue for meeting future energy needs while minimizing environmental impact.

I. Introduction

During the past twenty years the interest in rectifying units has been rapidly growing mainly due to the increasing concern of the electric utilities and end users about the harmonic pollution in the power system. As a result, pulse width-modulated (PWM) rectifiers have been of particular interest and they have become attractive especially in industrial variable-speed drive applications in the power range from a couple of kilowatts up to several megawatts. This is partly due to the reduced costs and improved performance of both the power and control electronics components but most of all due to the numerous benefits the using of the PWM Inverter offers.

There has been a need to control disturbances to the supply network almost since it was first constructed in the late 19th century. The first of these was the British Lighting Clauses Act of 1899 that prevented uncontrolled arc-lamps from causing flicker on incandescent lamps. With the growth of electronic equipment in the 1970's, it became necessary to control the disturbances caused by these increasing electronic equipment.

The growth of consumer electronics has meant that the average home has a plethora of mains driven electronic devices and not just television sets. Invariably these

electronic devices have mains rectification circuits, which is the dominant cause of mains harmonic distortion. Most modern electrical and electronic apparatus use some form of ac to dc power supply within their architecture and it is these supplies that draw pulsesof current from the ac network during each half cycle of the supply waveform. The amount of reactive power

drawn by a single apparatus (a domestic television forexample) may be small, but within a typical street there may be 100 or more TVs drawing reactive power from the same supply phase resulting in a significant amount of reactive current flow and generation of harmonics. Power electronic converters are becoming more popular in industrial, commercial and residential applications for reducing size and weight, as well as for increasing performance and functionality.

PV systems are like every different electric power generating systems; simply the instrumentation used is completely different than that used for typical electromechanical generating systems. However, the principles of operation and interfacing with different electrical systems stay an equivalent, and are guided by a well-established body of electrical codes and standards.

Although a PV array produces power once exposed to daylight, variety of different parts are needed to properly conduct, control, convert, distribute, and store the energy made by the array.

Depending on the useful and operational necessities of the system, the precise parts needed could include major parts like a DC-AC power inverter, battery bank, system and battery controller, auxiliary energy sources and typically the desired electrical load (appliances). Additionally, an assortment of balance of system (BOS) hardware, as well as wiring, overcurrent, surge protection and disconnect devices, and different power process instrumentation.

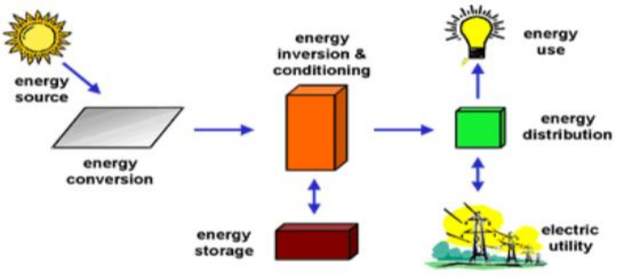


Fig.1 PV System

Wind results from air to motion. Air in motion arises from a pressure gradient. Wind is basically caused by the solar energy irradiating the earth. This is why wind utilization is considered as a part of solar technology. Wind power is the use of air flow through wind turbines to mechanically power generators for electricity. Wind power is plentiful, renewable, widely distributed, clean, produces no green house gas emissions during operation, consumes no water and uses little land. The net effects on the environment are far less problematic than those of non-renewable power sources. Wind is the movement of air across the surface of earth, affected by areas of high pressure of low pressure. Wind energy conversion devices are commonly known as wind turbines because they convert the energy of the wind stream into energy of rotation.

II. Overview of voltage source PWM inverter

Pulse-width modulation inverters take in a constant dc voltage. The inverter should conduct the magnitude and the frequency of ac output voltages, and the diode rectifiers are required to fix the line to line voltage. The inverter uses pulse-width modulation using it's switches, there are various methods for doing the pulse-width modulation in an inverter beneficial to frame the output ac voltages nearly similar to sine wave. The inverter only controls the frequency of the output where the input voltage controllers the magnitude. The ac output voltages get a waveform identical to a square wave to which the inverter got its name. In ac-motor drives the switch-mode dc-to-ac inverters are applied and uninterruptible supplies of ac power where the central equitable is to provide a sinusoidal ac output where magnitude and frequency the couple can be controlled. Micro-inverters converts direct current from individual solar panels on to alternating current for the electric grid, they are grid tied. The Photovoltaic inverter can be supplied into a profitable electrical grid or can be used in an off-grid. Photovoltaic inverters have positive functions fitted for the use with photovoltaic arrays, as well as anti-islanding protection and maximum power point tracking. An inverter converts the DC electricity to AC electricity from sources like fuel cells and batteries. The electricity required voltage,particularly it can keep AC equipment design for main operation and improved to yield DC at any crave voltage. In inverters the power semiconductors devices always remains forward-biased due to the supply voltage, and therefore, self-controlled forward device such as IGBTs and MOSFETs are suitable.

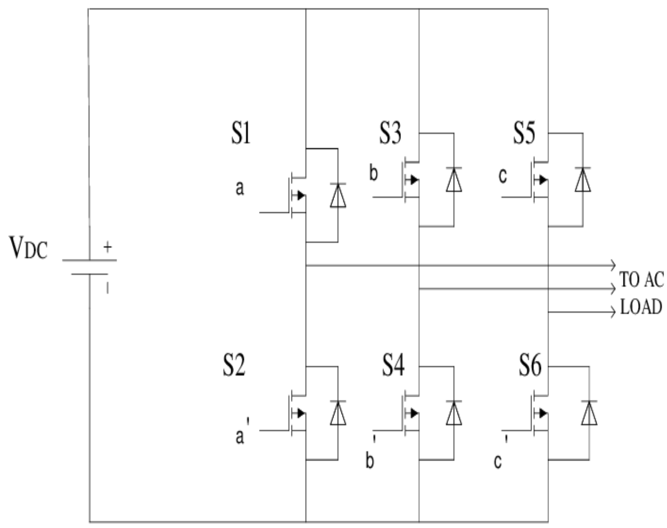


Fig.2 voltage source PWM inverter connected with load

III. Proposed MethodologyMPPT (P&O)

III.1. Definition of MPPT

- MPPT or Maximum power point tracking is an algorithm that is included in charge controllers used for extracting maximum available power from wind generator system.
- A MPPT or maximum power point tracker is an electronic DC to DC converter that optimizes the match b/w wind generator and the battery bank / utility grid.
- MPPT is DC to DC converter which operates by taking DC i/p from wind generator, changing it back to a different DC voltage & current to exactly match the wind to generator to charge the battery.
- The technology of MPPT is employed to increase the efficiency of wind energy system as they are designed for peak power extraction also, they attempt to pull the max possible electrical power from a given wind turbine under the current wind conditions.

III.2. Function of MPPT

i. A maximum power point tracking (MPPT) algorithm increases the power conversion efficiency by regulating the turbine rotor speed according to actual wind speeds.

ii. It makes sure that battery discharge current is within specified limit.

iii. It also protects the buck converter from over current situation.

iv. To enhance the efficiency and economics of wind energy conversion systems (WECS)

III.3. Working of MPPT

Please The MPPT algorithm proposed to track the MPP by perpetually adjusting the inductor current to reach the MPP. The dc-link voltage is not controlled. Thus, it will be monitored and the natural comportment of the dc voltage during wind speed change will be acclimating to enhance the tracking speed of the algorithm. The algorithm works in two distinct modes: The normal P&O mode under slow wind fluctuation conditions in which an adaptive step size is employed with the power increment utilized as a scaling variable. The second mode is the predictive mode under sudden wind speed change conditions; this mode is responsible for bringing the operating point to the vicinity of the MPP during expeditious wind speed change, and it will avail obviate the generator from stalling by rapidly adjusting the generator torque in replication to sudden drops in wind speed.[27]

In this mode, the dc-link voltage slope is utilized as a scaling variable and is utilized to determine the next perturbation direction. Proposed MPPT algorithm will run as mundane adaptive step size P&O algorithm unless a wind speed change causes the system to rapidly expedite or decelerate. In this case, the system will counteract the expedition/deceleration by transmuting the reference current felicitously and moving the operating point much more proximate to the incipient MPP. Then, the algorithm will then resume normal P&O mode. This method results in a saliently conspicuous tracking speed enhancement. More importantly, the system is averted from sudden stalling during sudden wind speed reductions.[26].

III.4. P& O (Perturbation & Observation)

In this control scheme we use P&O method. In any mppt technique two inputs are taken one is voltage (v) and second one is current(i). Perturbation variable as dc current is used in our proposed scheme.

The perturbation and observation (P&O), or hill-climb searching (HCS) method is a mathematical optimization technique used to search for the local optimum point of a given function. It is widely used in wind energy systems to determine the optimal operating point that will maximize the extracted energy. This method is based on perturbing a control variable in small step-size and observing the resulting changes in the target function until the slope becomes zero. P&O control adjusts the turbine speed toward the MPP, according to the result of comparison between successive wind turbine generator output power measurements. It is especially suitable for small-scale WECSs, as an anemometer is not required and the system knowledge is not needed.[25]

The Perturbation is opted as one of following conditions.

i. Perturb the rotational speed and observed the mechanical power.

ii. Monitor the output power of generator and perturb the inverter input voltage

iii. Monitor the output power of the generator and perturbed the converter variables i.e

Duty cycle, output current, input voltage.

To improve the efficiency and the accuracy of the conventional P&O method, modified variable step-size algorithms have been proposed. In adaptive step-size methods, the step-size is automatically updated according to the operating point. If the system is working on a certain point that is far from the peak, the step-size should be increased to speed up the tracking process. Conversely, the action is reversed to decrease the step-size when the operating point nears the MPP. The step-size is continually decreased until it approaches zero in order to drive the operating point to settle down exactly at the peak point.[22] This working principle reduces the oscillations that occur in the conventional P&O method, accelerates the speed to reach the maximum, and lowers the time for tracking.

IV. Simulation Results

Simulink provides a graphical editor, customizable block libraries, and solvers for modelling and simulating dynamic systems. It is integrated with MATLAB ®, enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis.

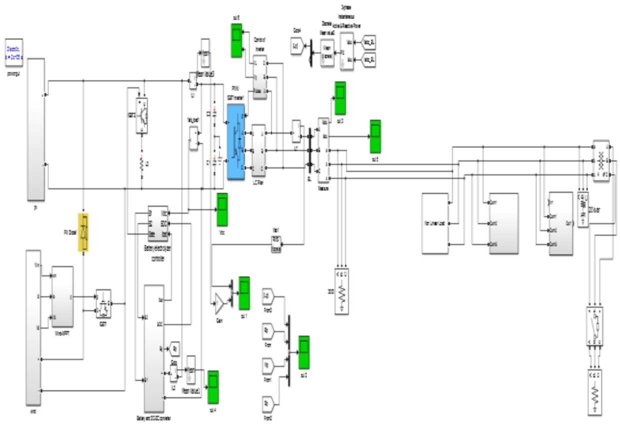


Fig.3 Proposed Model

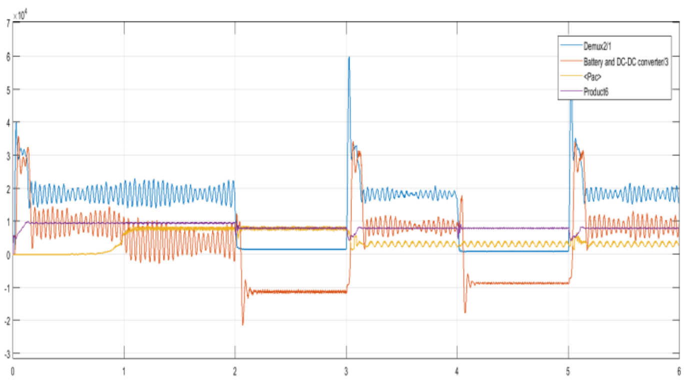


Fig.4 Simulation result of the power management when PV and Wind supplies load

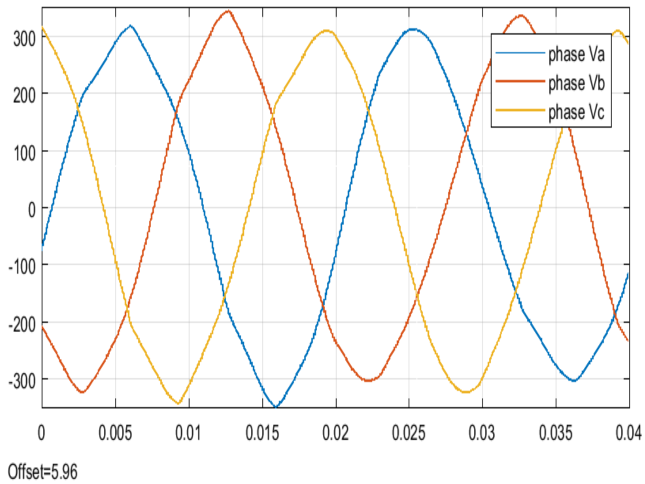


Fig. 5 Three Phase Out put Voltage

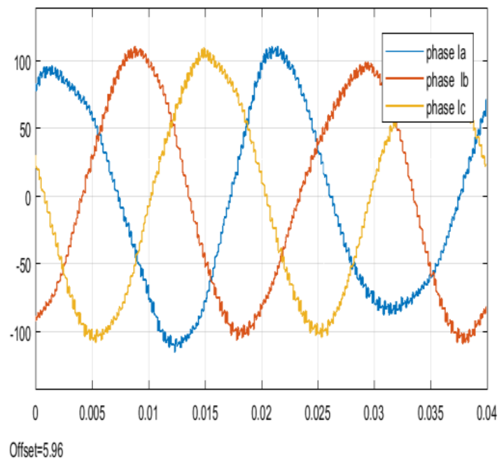


Fig.6 Three Phase Out put Current

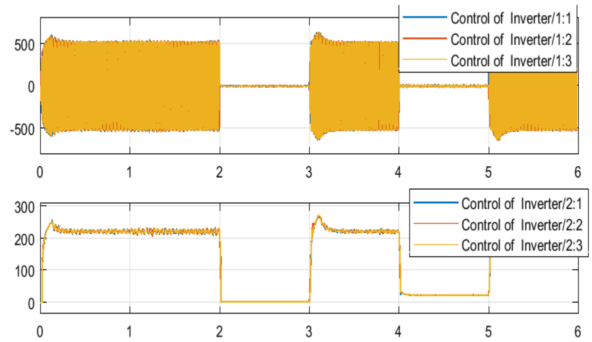


Fig. 7 Inverter Controlled Output of Voltage and Current

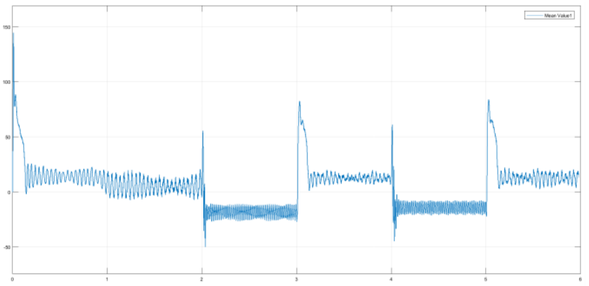
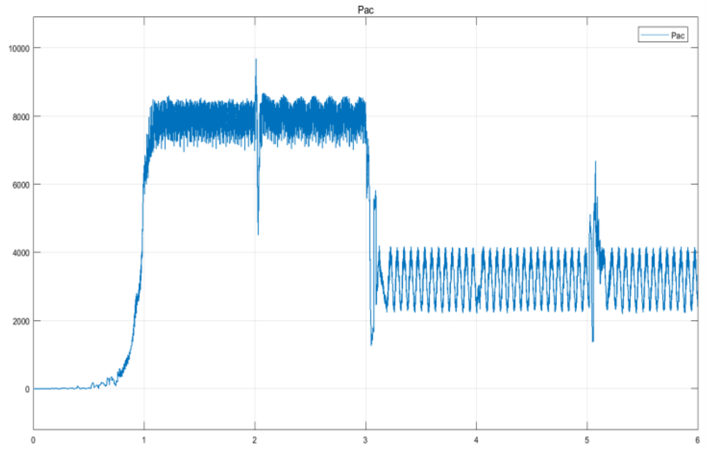
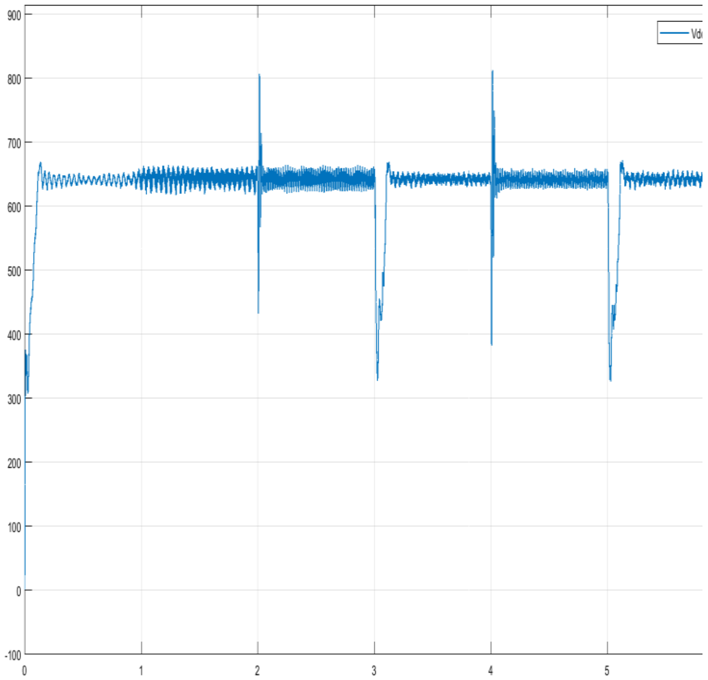


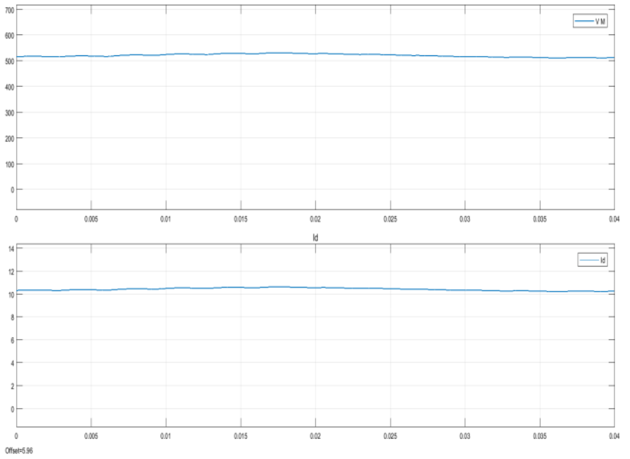
Fig. 9 PV Power



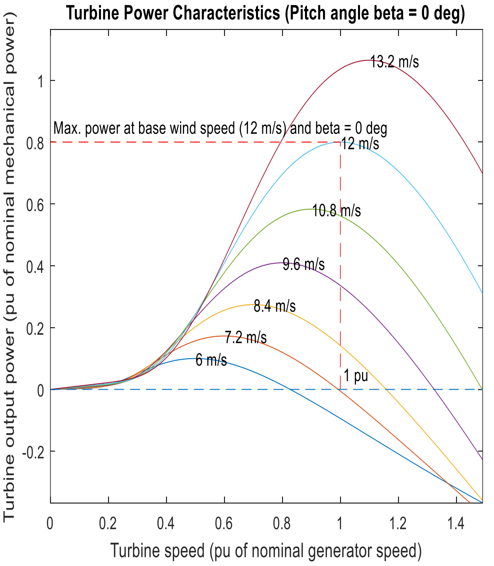
Generating Wind power



PV Voltage With MPPT



Voltage and current measurement when Nonlinear Load connected with hybrid system



V. Conclusion

Proposed work reduces the total harmonic distortion and the system power quality is improved using maximum power point tracking, wind power, PV cell and three phase pulse width modulated. In the meantime, the harmonic current brought on by the nonlinear load and the principal converter is repaid by the second converter. Consequently, the nature of the network current and the supply voltage are both essentially progressed. To lessen the computational heap of DG interfacing converter, the organized voltage and current control without utilizing load current/supply voltage harmonic extractions or stage bolt loops is produced to acknowledge composing control of parallel converters.

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