A Swift and Novel Method for Sensor less Speed Control of Induction Motor Application in Wind Energy

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Abstract— *this thesis presents a novel mechanical sensor less adaptive control algorithm for Maximum Power Point Tracking (MPPT) in Wind Energy Conversion Systems (WECS). The proposed control algorithm allows the generator to track the optimal operation points of the wind turbine system under fluctuating wind conditions using an efficient two-step process. This algorithm does not require the knowledge of turbine mechanical characteristics such as its power coefficient curve, power or torque characteristic. The characteristics of a wind turbine for any wind speed in a controlled test environment without depending on natural wind resources and actual wind turbine. A two-step MPPT technique has been proposed that addresses the problems that exist in the conventional hill-climbing. The proposed controller initially detects the optimal cubic power curve by deriving the optimal duty ratio from the boost chopper generation control Hardware implementation of WTTBS corroborates the simulation results. The Wind Turbine Test Bench System (WTTBS) uses an induction motor as a prime mover to replicate the behaviour of a wind turbine shaft. The brain of WTTBS is a Digital Signal Processor (DSP) based algorithm which controls the motor. The simulations for the test bench system were carried out in MATLAB/SIMULINK.*

Keywords— Wind Energy Conversion System, Wind Turbine Test Bench, Maximum Power Point Tracking (MPPT)

I. INTRODUCTION

Wind power is an affordable, efficient and abundant source of domestic electricity. It is pollution-free and cost-competitive in comparison to the energy from new coal and gas-fired power plants in many regions. The wind industry has been growing rapidly in recent years.. However, due to wind’s highly erratic nature, an intelligent control strategy must be implemented to harvest as much potential wind energy as possible while it is available. Because of the merits, and recent technological advancements in wind turbine aerodynamics and power electronic interfaces, wind energy is considered to be an excellent supplementary energy source. Research to extract the maximum power out of the available wind energy is an essential part of making wind energy much more viable and attractive.

Due to the critical condition of industrial fuels which include oil, gas and others, the development of renewable energy sources is continuously improving. This is the reason why renewable energy sources have become more important these days. Few other reasons include advantages like abundant availability in nature, eco-friendly and recyclable. Many renewable energy sources like solar, wind, hydel and tidal are there. Among these renewable sources solar and wind energy are the world’s fastest growing energy resources. With no emission of pollutants, energy conversion is done through wind.

Day by day, the demand for electricity is rapidly increasing. But the available base load plants are not able to supply electricity as per demand. So these energy sources can be used to bridge the gap between supply and demand during peak loads. This kind of small scale stand-alone power generating systems can also be used in remote areas where conventional power generation is impractical.

The entire system simulink model the wind systems. The simulink model of is powered by the wind energy which is abundantly available in nature. Maximum power point tracing systems make the wind energy system.. The maximum power point tracking system with Perturb & absorb algorithm is used, which extracts the maximum possible power. The ac-dc converter is used to converter ac voltage to dc.

A. Advantages of Wind Energy

- Wind energy produces no polluting emissions of any kind, including those that cause global warming.
- Wind turbines use a fuel that is free, inexhaustible and immune from the drastic price swings to which fossil fuels are subject.

With careful sitting and outreach to the local community, wind farms can be built in a fraction of the time it takes to construct coal or natural-gas power plants. A 50-megawatt wind farm can be completed in less than a year.

When installed at the right location, it takes only three to eight months for a wind energy farm to recoup the energy consumed by its building and installation, one of the fastest "energy payback times" of any energy technology on the market.

Wind power consumes no water during operation. This will be an increasingly important attribute as the water-energy nexus grows in importance and as water use becomes an increasingly important facet of defining sustainability.

B. Wind Energy Conversion Principle

Energy available in wind is basically the kinetic energy of large masses of air moving over the earth’s surface. Blades of the wind turbine receive this kinetic energy, which is then transformed to mechanical or electrical forms, depending on the end use. The efficiency of converting wind to other useful energy forms greatly depends on the efficiency with which the rotor interacts with the wind stream.

C. Sensor Less Induction Motor

The stator is connected to the utility grid to provide the necessary magnetizing for machines operation. The rotor on the other hand is connected to the grid through power converters as shown in Fig 1. The rotor side converter regulates the electromagnetic torque and supplies some of the reactive power. To enable regulation of the electromagnetic torque, algorithms for extracting maximum power are implemented in the rotor side converter stage. The controller of the utility side converter regulates the voltage across the DC link for power transmission to the grid.

There are reduced inverter costs associated with the Doubly Fed Induction Generator (DFIG) wind turbine because the power converters only need to control the slip power of the rotor. Another advantage of the DFIG is its two degrees of freedom; the power flow can be regulated between the two wind systems (rotor and stator).

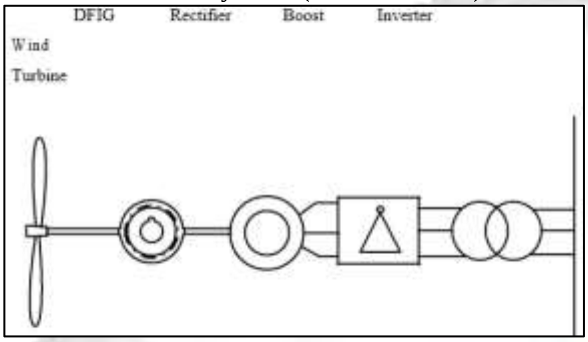

Fig. 1: DFIG based Wind Energy Conversion System

This feature allows minimization of losses associated at a given operating point as well as other performance enhancements. A disadvantage of using the DFIG wind turbine, however, is that the generator uses slip rings. Since slip rings must be replaced periodically, and so the use of DFIG's translates to more frequent maintenance issues and long term costs than other brushless Motor

D. Wind Turbine Test Bench Systems

Design and development of WECS necessitates the need of detailed design processes to determine the best configuration, suitable location and a maximum power point tracking method, all of which requires numerous onsite experiments. Hence an accurate Wind Turbine Test Bench System (WTTBS) is required to validate the design of laboratory concept prototypes. The WTTBS should be able to reproduce the characteristics of a real wind turbine for any given wind speed without depending on the natural wind. These systems can improve the effectiveness and efficiency of research in WECS. A WTTBS essentially consists of a torque controlled electrical motor and a controller.

II. PROBLEM IDENTIFICATION

The Existing HCS algorithm is most commonly used because of its ease of implementation. It is based on the following rule of thumb: if the operating power of the wind turbine is perturbed in a given direction and if the power drawn from the wind turbine increases, this means that the operating point has moved toward the MPP and, therefore, the operating power must be further perturbed in the same direction. Otherwise, if the power drawn from the wind turbine decreases, the operating point has moved away from the MPP and, therefore, the direction of the operating power perturbation must be reversed. However, a drawback of Hill Climbing MPPT technique is that, at steady state, the operating point oscillates around the MPP resulting in waste of some of the available energy.

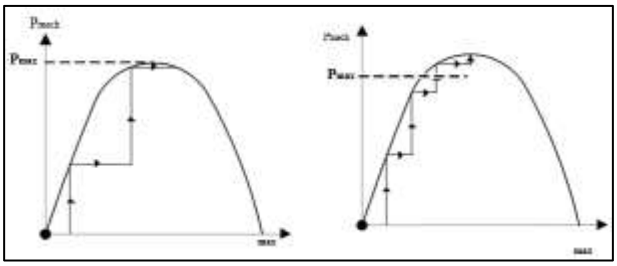

Fig. 2: Conventional Hill climbing perturbation

This can be seen in Fig 2 a larger perturbation step size increases the speed of convergence but deteriorates the efficiency of the MPPT by amplifying the oscillations around the MPP Pmax. This is because the HCS control does not at stop the process at MPP since it does not possess a peak detection capability, and hence, the oscillations are an unavoidable attribute of the HCS control. A smaller step size boosts the efficiency, but then, the convergence speed becomes slower; therefore, the controller may become incapable of tracking MPP under rapidly varying wind conditions. Hence, in the conventional HCS control, a trade off always exists between the tracking speed and the control efficiency.

In the existing HCS algorithm, the direction of the next perturbation depends on the change in power due to the previous perturbation. Since the HCS algorithms treats the rest of the system as a black box , this rule can be overtly misleading , as the sign of the imminent perturbation might be caused by the wind change rather than the applied perturbation . This logic leads to failure in keeping track of MPP and HCS algorithm moves downhill.

III. METHODOLOGY

Due to the rapidly varying wind conditions and generator load, optimal power characteristics, kopt is never unique for a given wind turbine. Hence to account for the non-uniqueness of kopt, the algorithm has to be fine-tuned to attain the absolute maximum power point. The proposed control incorporates a self-tuning strategy by a novel process of scanning.

The flowchart in Fig 3 shows the Initialization process and two steps of operation. Initialization process searches for a kopt with boost circuitry approach. Step 1 retains the system at the detected maximum, unless there is a change observed in wind velocity v. Step 1 gets into action under changing wind conditions and implements the novel Optimal Point search method via the earlier found kopt.

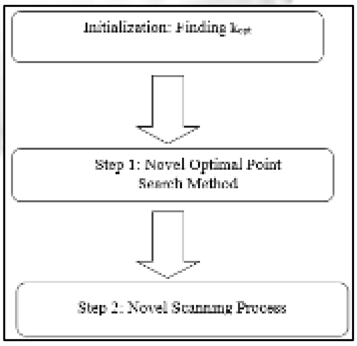

Fig. 3: Flow of the algorithm under various constraints

Step 1 may not yield the true MPP, owing to the non-uniqueness of kept for different wind velocities, but still, it drives the operating point in the close vicinity of the true peak power. This control is very useful for fast tracking. It is to be noted that the control input is the duty ratio D of the converter which is generated by the MPPT controller. Step 2 implements the Scanning process, which fine tunes the obtained maxima. In the Scanning process the Duty ratio is made 1. Due to the effect of inertia, the current takes some time to reach its short circuit value. During this period, the controller continuously computes the active power and stops the further increase in current once the maximum power is reached.

A. *Modelling of Test Bench System*

The objective of this chapter is to design a prototype of variable speed WECS simulator for a certain operational condition under variable wind speed. In this chapter variable sensor less speed induction motor drive using vector control is interfaced in WECS as an alternative to make the real time wind emulator for wind energy researchers as shown in Fig 4.

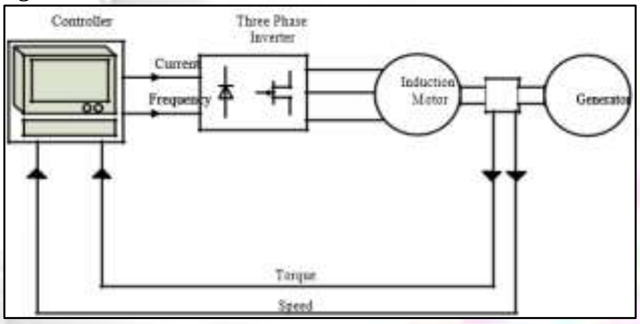

Fig. 4: Structure of Wind Turbine System

The basic power curve from wind generator is implemented using a Digital Signal Processor and interface of induction motor through an inverter control system. The induction motor is operated in a wide speed range using Field oriented control scheme. The laboratory prototype consists of 1/4 HP, 415 Volts, 60Hz induction motor controlled by a voltage source inverter for various wind speed. The result verifies that the wind turbine simulator can reproduce the steady state characteristics of a given wind turbine at various wind conditions. The steady-state wind turbine model is given by the power speed characteristics shown in Fig 4. The curves in Fig 4 represent the characteristics of a 8-kW, three blade horizontal axis wind turbine with a rotor diameter of 2.5 m. These curves can be obtained by wind turbine tests or calculated during the design by manufacturers. At a given wind speed, the operating point of the wind turbine is determined by the intersection between the turbine characteristic and the load characteristic. Usually, the turbine load is an electrical generator, such as an induction generator, synchronous generator, or permanent-magnet (PM) synchronous generator.

In a wind turbine test bench system, the power-speed characteristics of a wind turbine are physically implemented by an induction motor drive. The shaft power (Pm) and speed (n) of the induction motor represents the power and speed of the wind turbine rotor. An inverter fed IM is used to drive a load (i.e., a generator as if it were driven by a real wind turbine). In order to reproduce the turbine characteristics of Fig 4.3 in a laboratory, a DSP based control system is develop. The wind speed signal needed for the test bench system is supplied from wind profiles which can be obtained from measured wind data of a site or can be set in any artificial form by users. Thus, researchers can conduct their studies on wind turbine drive trains in a controllable test environment in replacement of an uncontrollable field one.

B. *Sensor less Induction Motor Modelling*

The space vector equations for three phase induction machines in any arbitrary reference frame. The aim of vector control is usually to decouple the stator current into flux producing and torque producing components (ids and iqs) respectively in order to obtain a decoupled control of flux and electromagnetic torque. The model of an induction machine is highly nonlinear and mutually couple. The complexity of the model is dictated by the purpose for which the model is employed. A simplified equivalent circuit model of an induction machine.sIt is used to develop an appropriate controller with an approximate input output model which relates the stator voltage input Vs , and the outputs, namely the angular speed *w*r and the developed torque Tm. The model is established based on the following assumptions. The dynamics of the subsystems are neglected as its time constant is smaller than the mechanical subsystem Saturation and parameters are neglected. Core losses of the machines are neglected. The impedance of magnetizing circuit is considered larger than the stator impedance. The stator terminal voltage Vs is approximately considered as air-gap flux generated emf Vm. The rotor induced voltage Vr 0 causes rotor current Ir 0 at a slip frequency *w*sl, which is limited by rotor resistance and reactance. The phase diagram represents Lm, Rs are the magnetizing inductance and stator resistance and Ls, Lr are the stator and rotor inductance referred to input. The induction model consists of an algebraic equation which governs the flux linkage *f* = Vs *w*e where *w*e is the supply frequency. The laboratory test bench system comprising of induction motor drive has to produce the same inertia that a real wind turbine produces in the field. Hence a Compensation torque is added to the Induction motor torque to accurately emulate the effect of large turbine rotor inertia for a given wind speed. The actual blade torque can be represented.

IV. SIMULATION AND RESULT

The WECS considered for system design consist of a 8500 W wind turbine rated at 13 m/s coupled to a PMSG. For the design of WTTBS, the wind turbine model is replaced by an induction motor of 5.5 kW.The figure shows the simulink model of Wind Energy Conversion system (WECS).

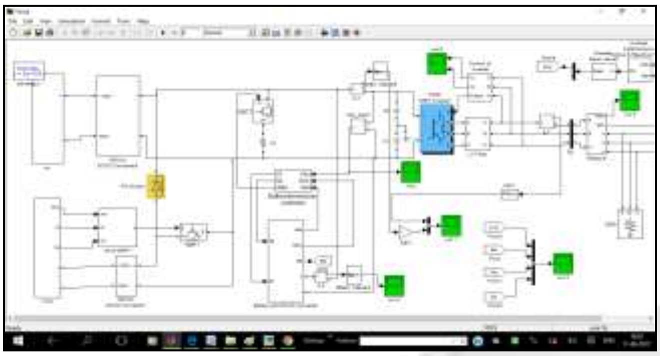

Fig. 5: Simulink model of wind power generation using sensor less induction motor

A. *Test Bench Emulation*

The behaviour of wind energy conversion system has been tested and analyzed for two scenarios. Scenario 1, Fig 6 emulates WECS with a wind turbine connected to PMSG and a load for 4 m/s wind speed. Scenario 2, Fig 7, emulates the same WECS configuration, but this time with an intelligent Induction motor drive instead of wind turbine. The initial disturbance in DC bus voltage indicates the presence of 3p oscillations as shown in scenario 2. The results of both the scenarios are compared. The PMSG is connected to the grid through a DC link capacitor. Fig 8 demonstrates the variation of system parameters for dynamic wind change. The results in Fig 9 also demonstrate the variation of Induction motor drive parameters with change in wind speed. Excellent similarity is observed between the simulation results of scenario 1 and scenario 2 which proves that WTTBS replicates the characteristics of a real wind turbine and wind turbine can be replaced by a WTTBS for laboratory emulation.

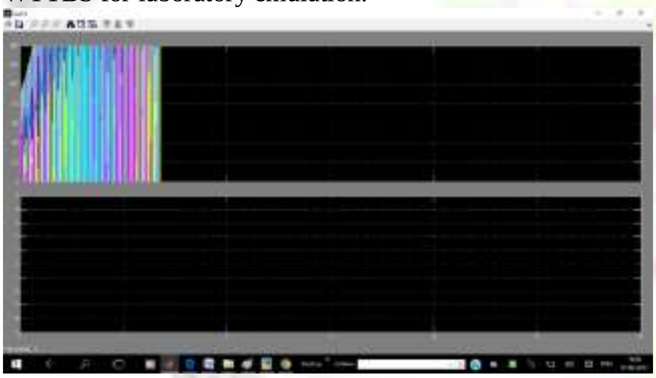

Fig. 6: WECS with a wind turbine connected to PMSG

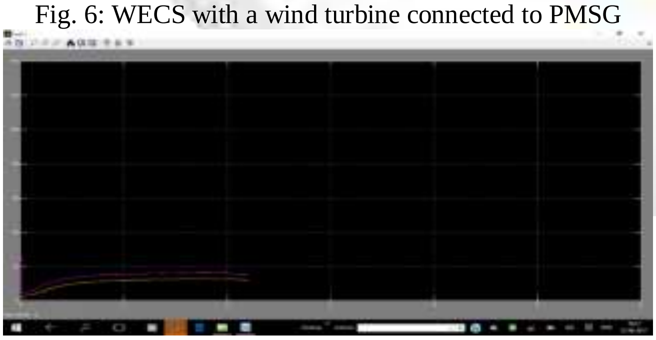

Fig. 7: An Intelligent Induction Motor Drive Instead Of Wind Turbine

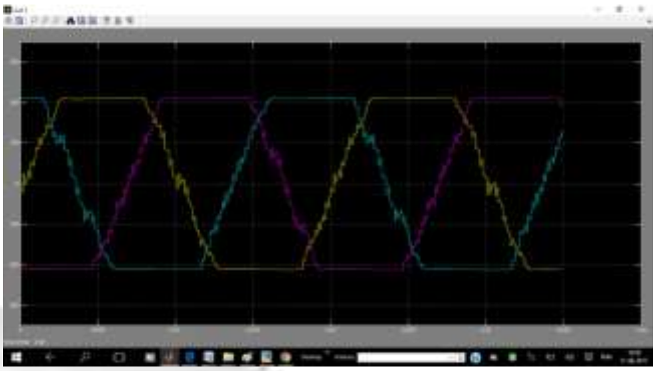

Fig. 8: Demonstrates The Variation Of System Parameters For Dynamic Wind Change

V. COMPUTATION PARAMETERS

Parameter	Value
Rated PMSG Power	9.1kW
No. of Poles Pair	5
PMSG Inertia	0.087 kg m^2
Rated Induction Motor Power	5.5 kW
Induction Motor Interia	0.089 kg m^2
Wind Turbine Rated Power	8.2 kW
Wind Turbine Inertia	128 kg m^2
Area of the Blade	5.89 m^2
Rated Turbine rooted speed	43.24 rad/sec

Table 1: Mechanical System Parameters

Wind Speed	W_{opt} [rad /sec]	$P_{mech,max}$ [Kw]	Torque [N-m]
3	10.78	126.3	11.7
4	14.44	299.3	20.7
5	18.00	584.5	32.4
6	21.56	1010.0	46.8
7	25.23	1603.9	63.5
8	28.79	2394.1	83.1
9	32.35	3406.8	105.3

Table 2: w_{opt} and $P_{mech,max}$ for various wind speeds

VI. CONCLUSION

The research proposed in this thesis aims at maximizing the efficiency of the wind energy conversion system by accurately predicting the Maximum Power Point (MPP). The conventional Hill climbing method relies on the perturbation step size for the accurate tracking of MPP. This causes the speed-efficiency trade off problem. The extracted average output power by the conventional MPPT techniques is drastically reduced due to these oscillations around the MPP.

A two step MPPT technique has been proposed that addresses the problems that exist in the conventional hill-climbing. The proposed controller initially detects the optimal cubic power curve by deriving the optimal duty ratio from the boost chopper generation control. This curve is used as a reference for the novel point search method to converge to the MPP. The point search method regulates the duty ratio of the boost converter (D) in an iterative fashion till the operating reaches the MPP along the optimal power curve.

VII. Future work

Design and development of WECS necessitates the need of detailed design processes to determine the best configuration, suitable location and a MPPT method, all of which requires numerous on site experiments. Hence an accurate Wind Turbine Test Bench System (WTTBS) can be effectively used to validate the design of laboratory concept prototypes. The bench system proposed in this thesis has to be integrated with the designed MPPT controller so that the entire system can be emulated in the laboratory.

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