Real Time Operational Analysis of Wind Energy Conversion System

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[**Received on:** 31/07/2021 **Accepted on**: 09/09/2021 **Published on:** 04/12/2021]

***Abstract*—The most dominant and invaluable alternative in wind energy development is that nations look forward to exploiting it for their electricity demand. Becoming a pollution free, limitless, and extremely cheap energy source, both industrial and emerging countries are becoming more and more common. That being said, optimum use of wind power generation in recent decades has remained a challenge for researchers. The wind turbine unit provides energy not obtained at an ideal level due to the extreme variational wind speed dynamics. There is a wind conversion system operation point which has a lot of significance for optimum power extraction. Wind speed calculation and focus on measuring system precision. They also reduce the efficiency of the control technique. The authors suggested a strategy of higher trust, low expenses, and less mechanical tension of the wind generator system (WGS) which is workable and can be used efficiently.**

***Index Terms*—Variable rpm, wind generator (WGS); method of maximum power tracking system (MPTS).**

I. INTRODUCTION

Today's world, because of rising costs and insufficient supply, renewable energy technologies replace traditional energy resources for power generation. From these different options for green energy including solar, wind, tidal, biomass, geothermal, hydro, wind energy has proved to be one of the cleanest alternative energy resources and is the most economical, sustainable, and environmentally friendly. The wind energy conversion device consists of electrical, mechanical, and wind power elements and converts it into electricity. The construction of the wind power conversion system must fix two critical problems. The first challenge is the difference of wind direction, where optimum wind strength must be tracked at different speeds. The second refers to wind turbine and generator aerodynamic rotor speeds and the sum of their generated wind energy. The peak power of the wind power system varies instantaneously during the day depending on wind and wind direction, which is why it is a challenge for the power engineer to monitor the wind Turbine maximum output at all wind speed. It is therefore helpful to suggest an empirical method results of experimental model that can monitor maximum power at variable speeds, and therefore

wind speed can only be unknown and unpredictable. Until actual implementation, several researchers create and simulate their proposed algorithm. Modelling and simulation can offer

an efficient way to analyze various wind conversion device parameters. However, an experimental model developed is a reasonable choice to better understand the nonlinear behavior of a wind turbine [1–3].

II. GENERATOR USED IN WIND ENERGY CONVERSION SYSTEM [4]

Wind Conversion System (WECS) generators are categorized in four major types:

A. Squirrel Cage Induction Generator (SCIG)

Contrary to WRIG, SCIG has a rotor consisting of longitudinal conductive bars and is mounted in grooves and short circuited by short rings with insular rotor curves that can be reached by slip rings and brasses. the challenges with WRIG and DFIG brushes and slip rings and BDFIG'S complexity was over in SCIG. therefore, of the four IG setups, SCIG is the smallest, the least cost and the most robust structural however, a WECS built on the SCIG calls for full capacity converters for optimum wind power to be harvested and completed. active as well as reactive power control. as an advanced computer SCIG-based wind turbine device have wind energy applications was of concern to many research ventures such as emulator plan, set-up of simulator, new power, and control transformers programs.

B. Wound Rotor Induction Generator (WRIG)

Wound Rotor induction generator are Variable Speed Resistance. For this sort of wind turbine, WRIGs are the only type. The rotor resistance adjustment and regulation of rotor current and the torque speed characteristic is done with this kind of generator. Although if it is working as a generator or motor, the induction generator still utilizes reactive power.

C. Doubly Fed Induction Generator (DFIG)

Doubly Fed Electric Generators are like electric AC generators; however, they have additional functions that enhance or decrease their normal synchronous speed at levels.

This is useful for wind turbines with high variable speeds as wind speeds will unexpectedly vary. if a wind force reaches a wind turbine, the blades attempt to speed up, but a synchronous generator is locked to the grid speed and is unable to accelerate. in the hub, transmission and generator as the power grid pushes back, large forces are created. This leads to wears and mechanical injury. If you cause the turbine to rotate as soon as it is hit by a windfall, so the power from the windfall is smaller, and is also transformed into beneficial energy.

D. Permanent magnet synchronous generator (PMSG)

Referring to WRSG, PMSG is an exciting synchronous generator that is brushless. permanent magnets create the magnetic rotor flow. the absence of rotor copper losses decreases the rotor thermal strain and ensures a high degree of strength. the reduction in the prices of permanent magnet and power converters made PMSG more compelling than WRSG after 1996. due to a drop in the expense of a permanent magnet and power converter PMSG has been more appealing than WRSG. However, the availability of permanent magnets and prices in the near future is actually strongly in doubt. This is partly attributed to small global providers and the potential effects of regulation on permanent magnet market stability.

TABLE I: SHOWS MACHINES USED IN WECS AND THEIR PROBLEMS ASSOCIATED [5]

S.NO:	(SCIG)	(PMSG)	(DFIG)	(WRIG)
1	Low Efficiency	High Efficiency	Very Sensitive to grid faults	Limited variable speed
2	Excitation capacitor required (external excitation)	Self-excited	Multi-stage gearbox is necessary (reliability issue)	Low power factor
3	Required gearboxes	Gearless drive	Existence of Brush/Slip ring	Need a reactive power compensator.
4	Gearbox losses & maintenance.	No rotor means no copper loss	Complex control of the entire unit	Use of many components

III. DYNAMIC SYSTEM MODELING [6]

A. Wind Turbine Simulator

For analyzing the real time data of WECS in laboratory methods required are as follows:

1) Motor Generator Set: In this method motor is used as wind turbine emulator that provides the same behavior of wind turbine used in WECS. In this method motor is driven at variable speed condition so that we can analyze the output of generator coupled with the motor can be analyzed under variable speed conditions.

2) Wind Tunnel: In this method an artificial air is created through a fan installed in tunnel, by varying speed of fan by variable voltage supply we can analyze the output of generator coupled with the Turbine (which is rotated with artificial air in real-time) under variable speed conditions. As we discussed variable source of wind energy is created by employing an artificial method of creating air using a fan driven by a motor.

3) Software Simulation: In this method no hardware is required for analyzing the characteristics of WECS but on other side, Software simulator is useful and simple, but there are several real-time analysis constraints. WECS hardware, typically known as a wind tunnel, typically constructed to produce an artificial wind speed operated for the operation of a wind energy conversion device, is needed for real time analysis. The prices of such hardware are, however, generally high. But several different wind simulators were suggested and built-in literature. The software simulator is fast and easy but has several real-time analysis constraints. An excellent alternative is to replicate the characteristic of the turbine utilizing wind tunnel to generate artificial air that enables one to maintain wind turbine performance and output in real time. The turbine is operated and managed for production in varying wind speeds of the wind turbine profile. Wind energy emulator system through creating an artificial air in laboratory are a valuable method for wind energy researchers to design and analyze wind energy systems. The WTE could be used to drive an electric generator connected with turbine which is placed in-front of wind tunnel in such way that can be moved in the same manner as a wind turbine for research applications by producing an artificial air through wind tunnel with a specified/variable wind speed. The wind simulator systems in the lab are usually deployed with inductive engines or DC motors and are an important instrument for research into wind energy generation.

IV. DYNAMIC SYSTEM MODEL OF WIND TURBINE

Fig: 4.1, 4.2, 4.3, for connection to real rotating blades and the motor for the simulation of wind turbine, the mechanic dynamic model of the wind turbine will be seen below.

$$T_{Blade} = (J_B + J_G)\ \frac{d\omega_{Blade}}{dt} + T_g \quad (4.0)$$

T_{Blade} The turbines produced mechanical torque and reflected inertia blades and inertia generator, with a speed of rotation of the rotor. In contrast to the engine torque, the blade torque Shows mechanical torque developed turbine and $J_B and\, J_G$ represent blades inertia and generators inertia and rotation blade shaft speed is represented by ω_{Blade}.

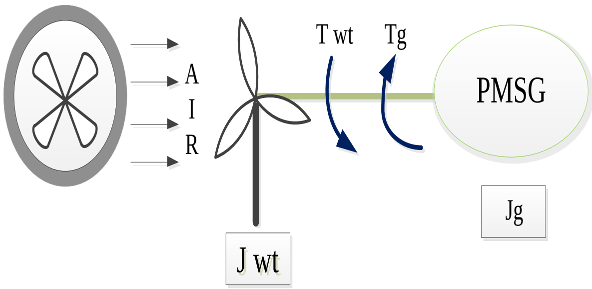

Fig.4.1: Model of turbine blade and generator

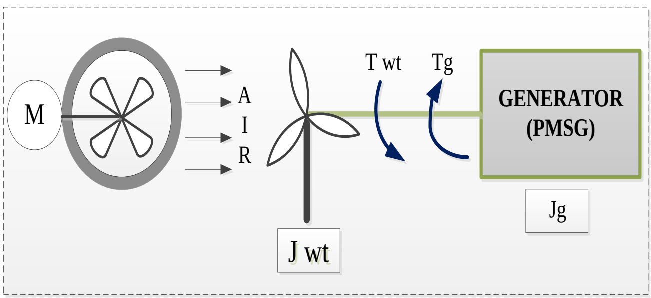

Fig.4.2: Model of Wind Tunnel, Turbine and Generator

The engine is used to simulate the same turbine action that the following equation can describe.

$$T_M = (J_M + J_G)\frac{d\omega_r}{dt} + T_g \qquad (4.21)$$

Where the torque motor represents Tm and the speed of the motor shaft rotation motor is expressed by W_r , which is represented by Jm.

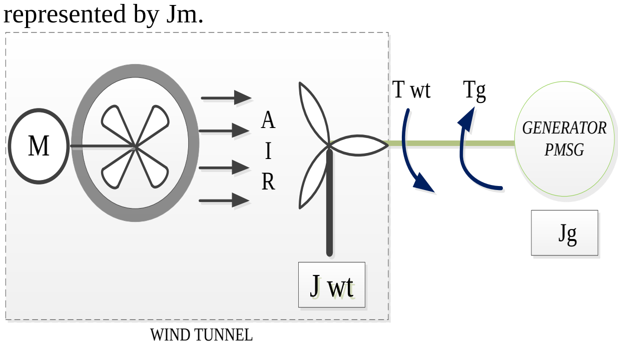

Fig.4.3: Model of Permanent Magnet Synchronous Generator and wind tunnel.

Key aim of this program is to use wind tunnel that is powered under variable speed conditions. This Variable Energy Conversion System application (WECS) uses a Permanent Magnet Synchronous Generator (PMSG), which is relatively cheap to construct in comparison to Squirrel Cage Induction generator and has low operating and maintenance costs in opposition to doubly-feed induction generators.

V. Modeling Of PMS Generator:

PMSG is characterized as a system that enables electricity from the mechanical energy produced from the wind to be produced. The PMSG's dynamic model derives from the two-phase synchronous reference framework, which, for the direction of rotation, takes the q-axis 90° ahead of it. A phase locked loop allows for synchronization between the d-q rotating frame and the abc-three phase frame (PLL). [7] The d-q reference framework used in a salient-pole synchronous machine (which is the same as the one used in a PMSG) shown in Fig 4.5 where e is the mechanical angle, the angle of the rotor d-axis to the axis of the stators.

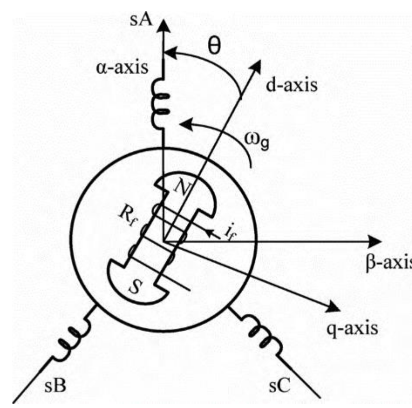

Fig-4.5: d-q and α-β axis of a typical salient-pole synchronous machine.

The PMSG mathematical model is often based on the following assumptions [8][9] for power system and converter system analysis: Stator windings shall not cause significant variations in rotor indictability with the rotor position, magnetic hysteresis and saturation effects shall be negligible, the stator slots shall be symmetric; the damping windings shall be not considered; the capacity of all windings shall be negligible; (this means that power losses are considered constant).

In the synchronous reference framework, the PMSG model is mathematically specified (in state equation form) is given by:

$$\frac{di_d}{dt} = \frac{1}{L_{ds} + L_{ls}}(-R\,i + \omega_e (L + L_{is})i + u)$$

$$\frac{di_q}{dt} = \frac{1}{L_{qs} + L_{ls}}(-R_s i_q - \omega_e[(L_{ds} + L_{ls})i_d + \psi_f] + u_q)$$

In those cases where the subscripts d and q are referring to the physical amounts changed into a d-q synchronous rotate reference frame, R, are resistor stators [n], L_d and L_q, the generator d and q axis inductance [H], Li_d and Ll_q, are

$$\omega_e = p\omega_g$$

inductors d and q axis, respectively, the *'PI* is the magnet flow permanent [W_b] and W_e is the generator's electrical rotary speed [rad/s], defined by:

Where p is a generator's number of pole pairs. The mechanical equation is required to complete the mathematical model of PMSG, and the accompanying electromagnetic torque equation explain it.

$$\tau_e = 1.5p((L_{ds} - L_{ls})i_d i_q + i_q \psi_f)$$

The comparable PMSG circuit in the de d-q rotating sync reference frame is shown in Fig. 10.

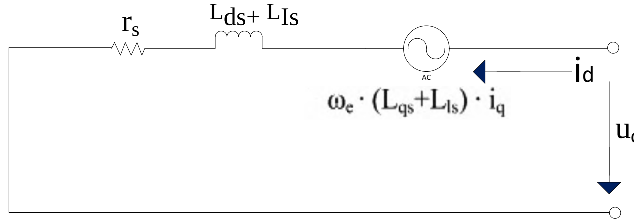

Fig:5.1: d-axis equivalent circuit

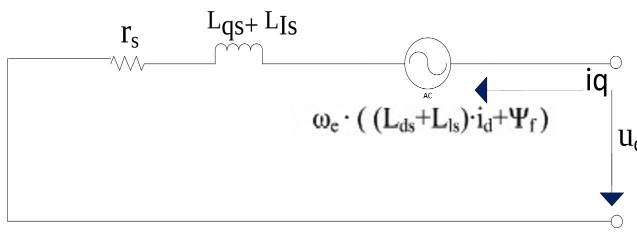

Fig:5.2: q-axis equivalent circuit

VI. MODELING OF OPTIMAL TRACKING CONTROLLER:

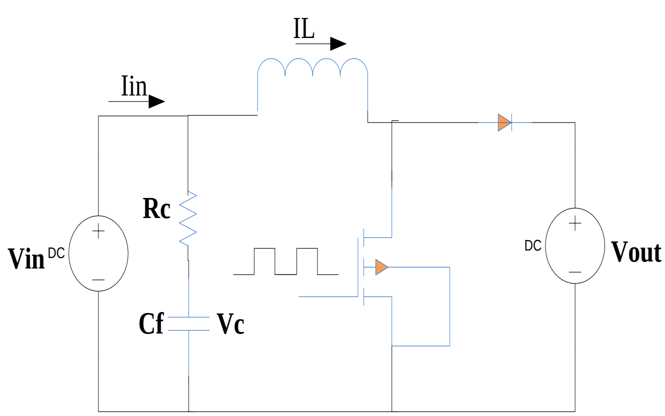

Fig.5.3: "DC-DC Tracker's equivalent circuit"

Fig 5.1,5.2 can be used to generate the state/input vectors as follows:

$$x = [V_c \quad i_L]^T ; u = [V_{dc} \quad i_o]^T \tag{5.11}$$

$$pi_L = \frac{1}{L}(R_{eq} C_f pV_c + V_c) \Rightarrow px_2 = \frac{1}{L}(R_{eq} C_f px_1 + x_1) \tag{5.12}$$

$$i_o = i_L R_{eq} C_f pV_c \Rightarrow i_o = x_2 + C_f px_1 \tag{5.13}$$

The state matrix of the dc/dc boost converter can be obtained during switching condition [10].

1) Case: During switch on condition:

$$p[x_1 \quad x_2]^T = A_1[x_1 \quad x_2]^T + B_1[V_{dc} \quad i_o]^T$$

where
$$A_1 = \begin{bmatrix} 0 & -\frac{1}{C_f} \\ \frac{1}{L} & -\frac{R_{eq}}{L} \end{bmatrix}, B_1 = \begin{bmatrix} 0 & \frac{1}{C_f} \\ 0 & \frac{R_{eq}}{L} \end{bmatrix} \tag{5.14}$$

2) Case: During switch off condition:

$$p[x_1 \quad x_2]^T = A_2[x_1 \quad x_2]^T + B_2[V_{dc} \quad i_o]^T$$

where
$$A_2 = A_1; B_2 = \begin{bmatrix} 0 & \frac{1}{C_f} \\ -\frac{1}{L} & \frac{R_{eq}}{L} \end{bmatrix} \tag{5.15}$$

VII. PROPOSED MTPS SYSTEM

In this article, the MPTS method is based on the continuous modification of the converter service cycle by power electronic topology, based on the comparability of successive output power measurements. The results of this paper are: Since the wind speed varies greatly in relation to time, due to the limited device reaction of the integrated WGS the power absorbed from the WGS shifts very slowly. Therefore, the problem of maximizing the output power of the WGS via the Power Electronic Converter via the working cycle is used as a control variable that can be specified as the following:

$$d_i = d_{i-1} + \frac{c_1}{\Delta d_{i-1}} \Delta P_{i-1} \quad (1)$$

Where d is the duty cycle, i and are the iterations values like $(0 < d_i < 1)$, $\Delta P_{i-1} / \Delta d_{i-1}$ is the WGS power Step gradient; and shift step. To ensure that the strategy suggested is converging at different wind speeds at a maximum point (MP). It is sufficient to show that the WGS and duty cycle function of the boost converter dc/dc is connected and has a single, optimal overlap of the WG MPTS point which is clearly visible in figure 1.

However, the features of the WGS force represented in Figure 1 are considered. The following can be specified for the full power generation system:

$$\frac{\partial P}{\partial \omega}=0$$

The following can be defined by applying the chain rule:

$$\frac{\partial P}{\partial \omega}=\frac{\partial P}{\partial d}\times\left(\frac{\partial d}{\partial V_\omega}\right)\times\left(\frac{\partial V_\omega}{\partial \omega_e}\right)\times\left(\frac{\partial \omega_e}{\partial V_\omega}\right)=0 \qquad (2)$$

And the ratio between input/output voltage and duty cycle can be described as follows when a dc/dc converter is applied:

$$d=\frac{V_0}{V_\omega}\Rightarrow\frac{\partial d}{\partial V_\omega}=-\frac{V_0}{(V_\omega)^2}\neq 0;$$

The speed relationships of the generator and the wind turbine are as follows:

$$\frac{\omega_e}{\omega}=pp\Rightarrow\frac{\partial \omega_e}{\partial \omega}=pp>0$$

Where pp is pair of poles.

VIII. EXPERIMENTAL SET UP AND DISCUSSION OF RESULTS

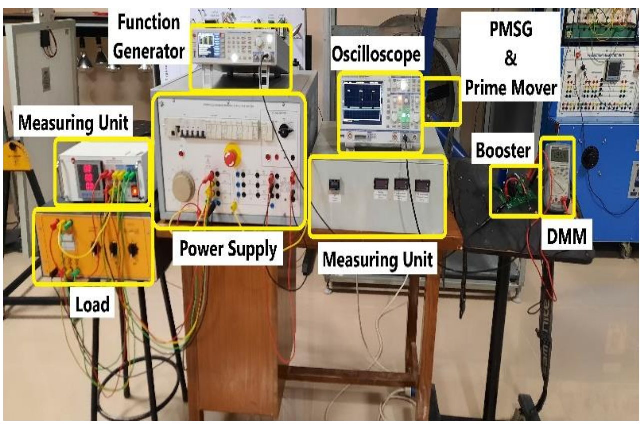

Fig.8.1: "Experimental Setup"

Fig. 8.1 indicates that the experimental MPTS was assembled using the above-described dc/dc tracker. On basis for the wind energy conversion system, the wind tunnel configuration was used based on fully experimental setup. In this configuration, the measured values are 27.5V, 3.2A and 88W respectively, for one MOSFET (Voltage and Ampere). The inductor value for outputs is 1.8 mH, 2.5 A and is engineered by Siemens E65/21, with a switching frequency of approximately 240 kHz and the input voltage of dc varies in sampling. The efficiency of a system response dependent on dc/dc boost converter is proven by the different duty cycle.

IX. EXPERIMENTAL MODEL DESIGN:

The experimental model for the wind generation system is shown in Figure.

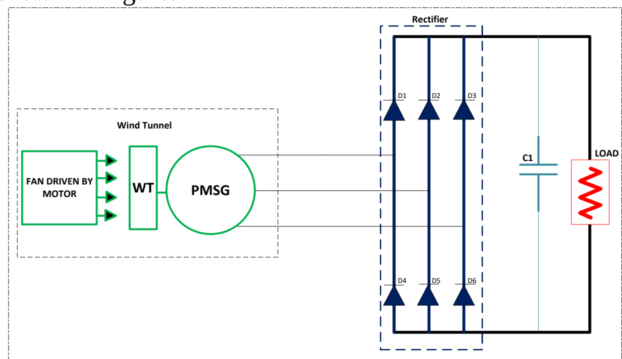

Fig: 9.1 Experimental circuit without tracker.

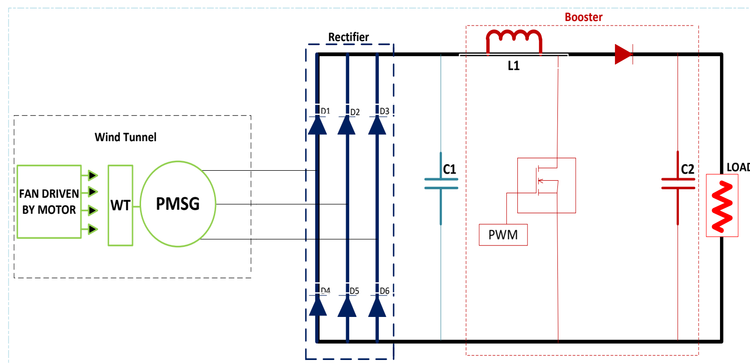

Fig: 9.2 Experimental circuit with tracker.

1) *Experimental Results and Discussion*

In order to test the efficiency of the wind Turbine System, an experimental model implementation of wind turbine conversion systems was completed with respect to the total power monitoring system results, by adjusting the rate of the prime mover at different times. Wind tunnel is the prime mover to create artificial air for the study of wind turbine behavior. Wind tunnel is placed in such a way that turbine is operated at a variable speed and wind-energy conversion system parameters such as speed, current, tension, and power were monitored without monitoring the wind-generator output technology and using the proposed wind-generating system output technology.

The permanent magnet synchronous generator is run at variable speed and its output capacity is analyzed in different time intervals.

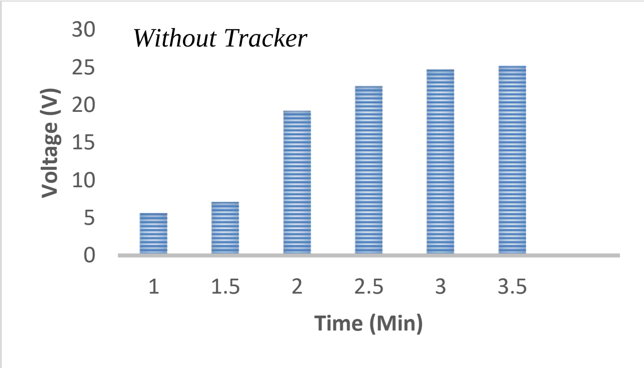

Fig 9.3 “Shows response of voltage at different time duration without Tracker”.

Figure 9.3 indicates the voltage response without Tracker at different times. The answer specifically showed that due to the change in speed condition, the voltage is 5.6 v to 25.18v(dc).

In the non-Tracker voltage response, we noticed that the dc voltage at different rpm was 5.6 v, 7.1 v, 19.23 v, 22.5 v, 24.7 v, 25.18 v, while the power voltage was analysed at different times on the DC-to DC booster and in the output rpm. The response voltage was 5.6 v, 8 v, 21.7 v, 23 v, 26 v, 27.5 v with booster and variable duty cycle. It can be noted that rpm used for Tracker was close to rpm without Tracker, which was used for analysis with Tracker rise. We also observed the voltage rises between 7.1 v to 8 v, 19.23 v to 21.7 v, 22.25 v to 26 v, 25.18 v to 27.5 v respectively. The voltage response at varying time with a Tracker is seen in figure 5.1,5.2.

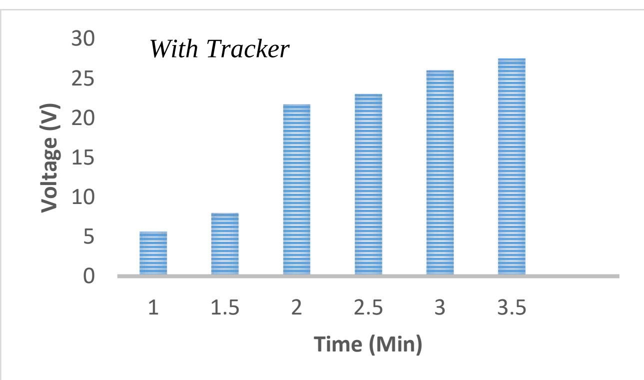

Fig 9.4 “Shows the response of voltage at different time duration with Tracker.”

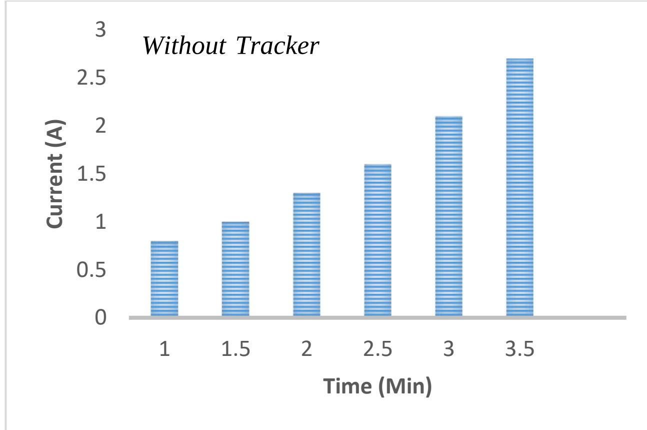

Fig 9.5 “Shows the response of current(A) at different time duration without tracker.”

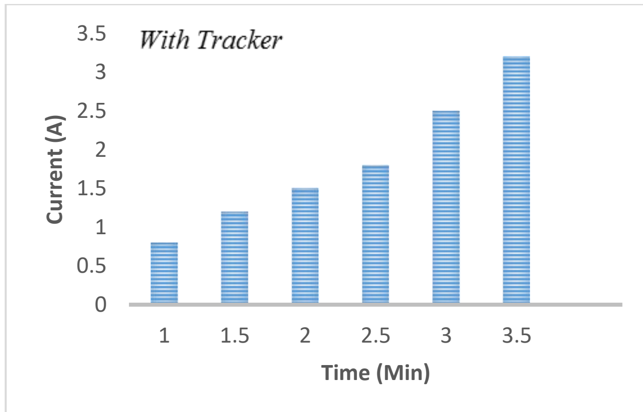

Fig 9.6 “Shows the response of current(A) at different time duration with tracker.”

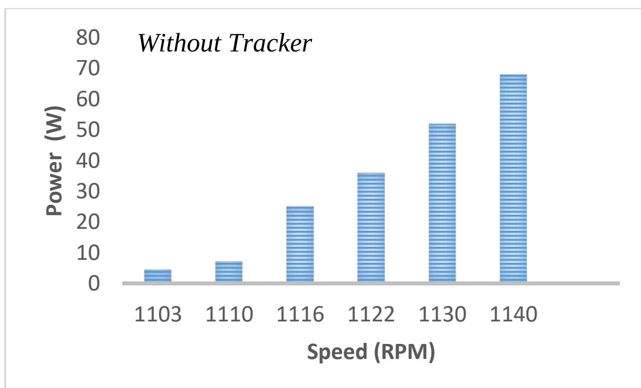

Fig 9.7 “Response of power with varying RPM without Tracker”

Figure 9.7 shows the speed response, which shows that the output power of the generator varies by the generator speed. Here, you can see that the generator has been active for the first time at 1103 minutes, and the power reaction was seen to be approximately less than 5 watts with speeds of 1110 minutes and 1116 minutes almost 20 watts difference was seen. We travelled with an observed power of 40 to 50 watts, from 1122 to 1130 minutes, and found a speed increase and vice versa. The principal goal of this study is to extract full power from the turbine by operating prime mover variable wind in tunnel under various speeds. Variable speed WECS also does not restrict the production of wind turbines in their full feasibility and cost-effectiveness, but wind turbines are uncertain and unstable and wind power generation is entirely subject to wind speed. WECS In order to obtain optimal power at varying speeds, a control technique may vary the speed of your generator in relation to wind turbines. In principle, this application uses the duty cycle as a control variable to adjust the generator speed in relation to the wind turbine. The pulse modulation technique used in DC-to-DC Trackers is used for the MOSFET portal in the proposed device service cycle. If speed is diverse, a generator output is observed, and the operating period is varied to the same degree to optimize energy by adjusting the energy conversion stage.

This MOSFET application duty cycle for the DC-to-DC Tracker ranged almost 20% to 50%. The operation cycles were fundamentally varied by a function generator with a potential to range from 20 to 80%, but this machine varied from 20% to 50% because the power output available was main and wind turbine.

As stated above, a continuous estimation without tracking methodology will analyze the performance of the generator to determine the value of tracking the full power at variable speed.

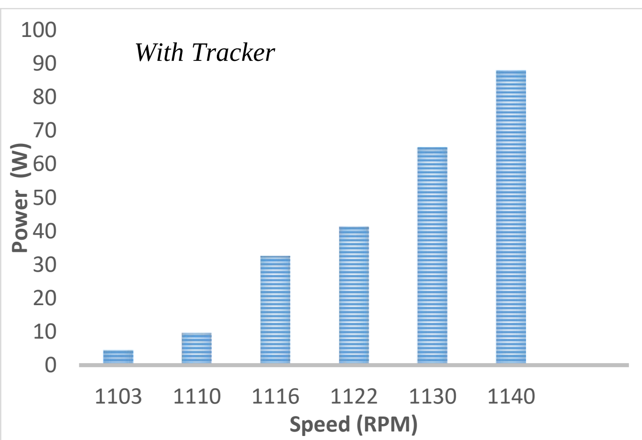

Fig 9.8 “Response of power with varying RPM with Tracker”

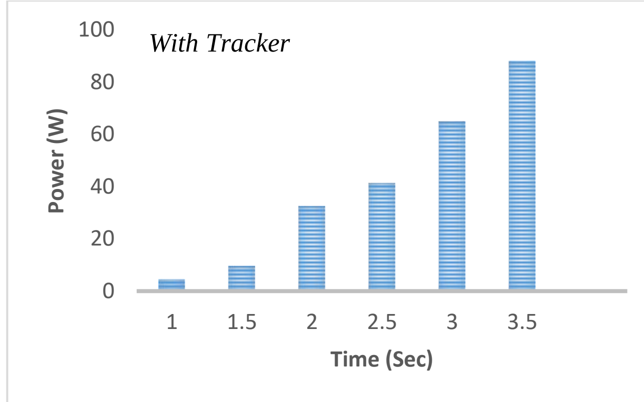

Fig 9.9 “Response of power with varying time(sec) with tracker”

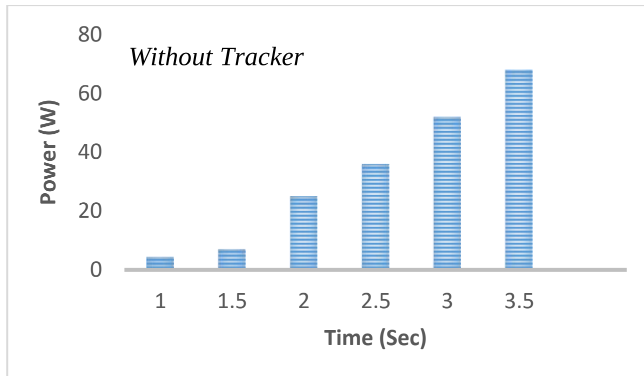

Fig 9.10 “Response of power with varying time(sec) without tracker”

X. Conclusions

A prototype test framework for the maximum power tracking system consists of a step-up DC/DC power converter was built in this study. There is no need to know about the optimum power features and wind speed of the planned MTPS technique. At a variable speed, the wind turbines run. But neither the wind speed and the rotor speed of the wind generator systems nor the power of dc/dc boost converters are responsible for the proposed MTPS. In addition, the experimental results of the proposed model portray the wind generator system productivity. The experimental findings of the proposed device show, by changing duty cycle compared to directly connected by a rectifier, that WGS power on the grid side is maximal on the grid side at 20-50%. The system proposed verifies that current wind energy is best used and that the minimum wind speed area is effective.

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