Design of Optimal Torque Control Method for Permanent-Magnet Synchronous Generator

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Abstract : Renewable energy has been developed recently because of the fossil fuel exhaustion and environmental problems. This paper presents a control strategy for the operation of a direct-driven permanent-magnet synchronous generator- based stand-alone variable-speed wind turbine. The battery charger employs a boost converter cascaded with a Greatz bridge that can harvest the maximum power from wind turbine. Also, a buck converter is connected in series with the boost stage to ensure a constant voltage. This system can extract maximum power over the entire wind speed range and the battery charging can be realized through conventional techniques. Simulation results are presented to depict the existence of maximum power points in wind generator. Extensive simulation results have been performed using MATLAB/SIMULINK.

Keywords: ***P****ermanent-magnet synchronous generator, stand-alone variable-speed wind turbine, boost converter, Greatz Bridge, buck converter.*

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I. INTRODUCTION

For the stand-alone wind power system, the load is a battery that can be considered as an energy sink with almost constant voltage. The battery can absorb any level of power as long as the charging current does not exceed its limitation. Since the voltage remains almost constant, but the current flows through it can be varied, the battery can be also considered as a load with a various resistance. Wind generators (WGs) have been widely used both in autonomous systems for power supplying remote loads and in grid-connected applications. Although WGs have a lower installation cost compared to photovoltaic's, the overall system cost can be further reduced using high-efficiency power converters, controlled such that the optimal power is acquired according to the current atmospheric conditions.

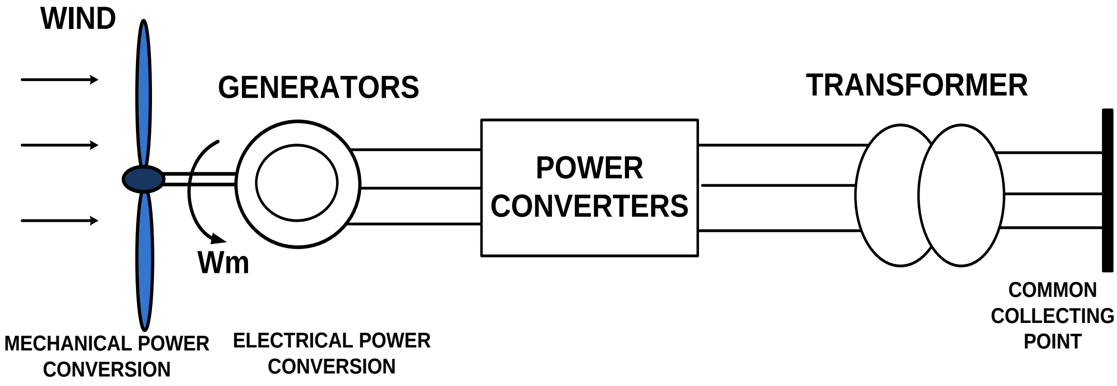
A simple structure to solve the previous problems is to use a boost converter cascaded with the Greatz bridge. Although this topology operates over the entire range of wind speed, this practice is not usual due to the necessity of high voltages i.e. many batteries in series. The buck-boost converter is another topology with a disadvantage that lies in the reversed output voltage. The use of semi-controlled rectifiers represents good solutions to improve the power factor in electrical machines, but the inclusion of extra switches and current sensors may cause the battery charger cost to increase significantly. PWM rectifiers are also a prominent solution, but they are more appropriated in medium and large systems due to high implementation cost.

The proposed battery charger presents a Greatz bridge associated with a boost converter and a buck converter. The Greatz Bridge is used to rectify the ac generated voltage. The boost converter is responsible for tracking the maximum power through a MPPT system over the full range of wind speed. It is also responsible for regulating the battery bank voltage, thus reducing the Permanent Magnet Synchronous Generator (PMSG) rotation due to high voltage levels that may appear across the battery. Finally, the buck converter is used to control the dc link in order to ensure constant voltage and the adequate interconnection of the aforementioned converters. Besides, the number of batteries connected to the battery charger can be properly adjusted. The disadvantage of the proposed topology is the use of many cascaded converters, leading to the reduction of the global efficiency of the battery charger.

The objective of this project is to design a power converter feasible for variable speed PMSG based small wind energy conversion systems and implement it in MATLAB/SIMULINK.

II. WIND ENERGY CONVERSIONS

The wind is created by the movement of atmospheric air mass as results of variation of atmospheric pressure, which results from the difference in solar heating of different parts of the earth surface. Wind power describes the process by which the wind is used to generate mechanical energy or electrical energy. Wind energy is the kinetic energy of the large mass of air over the earth surface. Wind turbines converts the kinetic energy of the wind into mechanical energy first and then into electricity if needed by means of generators. The energy in the wind turns propeller like blades around a rotor shaft. The rotor is connected to the main shaft, which spins a generator to create electricity. It is the design of the blades that is primarily responsible for converting the kinetic energy into mechanical energy. The rate of change of angular momentum of air at inlet and outlet of a blade gives rise to the mechanical torque. The general arrangement of wind energy conversion system is shown in fig(1).



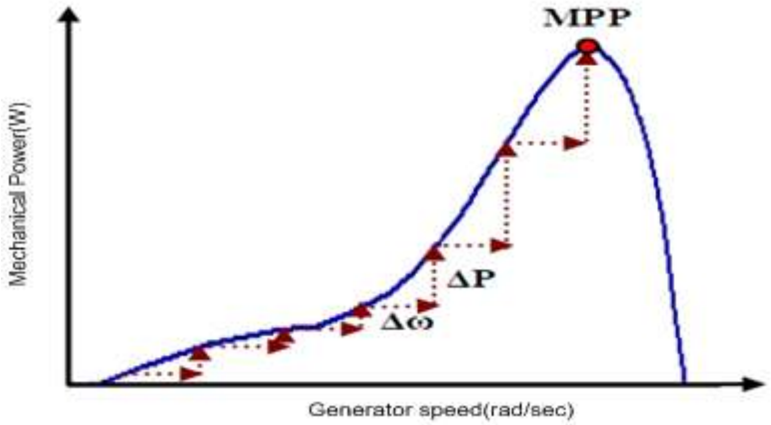
Fig(1) : Wind Energy conversion system

HILL-CLIMB SEARCH (HCS) CONTROL:

The HCS control algorithm continuously searches for the peak power of the wind turbine. Hill climb Searching is widely used in wind energy systems to determine the optimal operating point that will maximize the extracted power. This control is base on perturbing a control variable with a step and observing the resulting, the power previously delivered is compares with the one after disturbance. Choosing an appropriate step size is not an easy task: larger step-size means a faster response and much oscillation around the peak point, and hence, deteriorates the efficiency. A smaller step-size improves the efficiency but the controller will become very slow, as shown in Fig(2). There is a Trade off between the tracking speed and the control efficiency.

The magnitude of the step-size is the main factor determining the amplitude of oscillations and hence the convergence rate to the final response. To overcome this trade-off, the step-size of varying amplitude can be applied. The step-size amplitude can be determined according to power variations based on the previously applied disturbance. Therefore, larger step-size amplitude is selected when power is far from MPP due to the larger magnitude of P_m (ω_m) slope and small amplitude is selected when power is close to MPP. The step-size is continually decreased until it approaches zero in the aim to drive the operating point to settle down at the MPP.

A disadvantage of HCS method, described by fig(3), appears (in blue colour) in the case of a sudden increase of wind speed, where the algorithm responds as if the increase occurred as a result of the previous perturbation of the operating speed.



Fig(2) : HCS Control for small perturbation

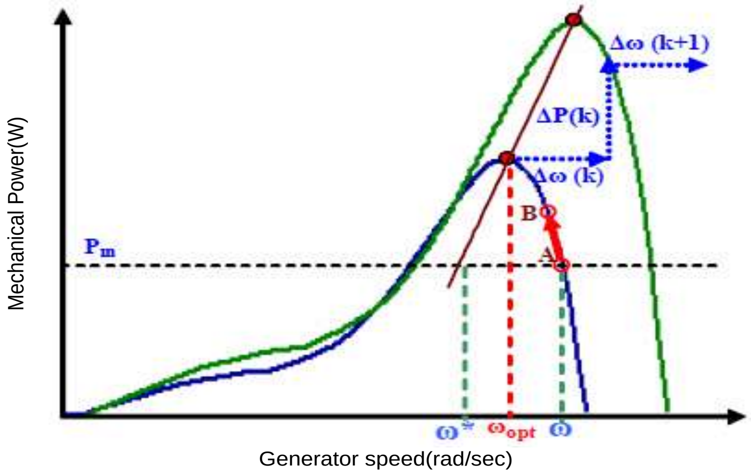


Fig.(3) : Deviation from the MPP with the HCS algorithm under rapidly changing wind conditions

III. DESIGN OF PROPOSED CONVERTER

The systems that use batteries demand an electronic circuit to control the charging and discharging process of the battery bank. The direct connection of a three-phase rectifier to batteries is a common practice adopted by some manufacturers. Although there is simplicity and robustness, several problems associated with this solution result, such as the reduction of batteries useful life and increase of power losses.

In order to solve these problems, many alternative solutions are presented such as the association of a buck converter in series with a Greatz bridge to extract the maximum power of the turbine. However, this topology does not deliver power to load when the generated peak voltage is less than the battery voltage. Other solution is to use a boost converter in parallel with the Greatz bridge to regulate the input voltage of the battery charger, while the generated voltage is not able to forward bias the rectifier diodes. Besides, such method does not allow tracking the maximum power for medium and high wind speeds. A simple structure to solve the previous problems is to use a boost converter cascaded with the Greatz bridge. Although this topology operates over the entire range of wind speed, this practice is not usual due to the necessity of high voltages i.e. many batteries in series. The buck-boost converter is other topology already studied in, but its disadvantage lies in the reversed output voltage. The use of semi controlled rectifiers as in represents good solutions to improve the power factor in electrical machines, but the inclusion of extra switches and current sensors may cause the battery charger cost to increase significantly. PWM rectifiers are also a prominent solution, but they are more appropriated in medium and large systems due to high implementation cost.

The proposed charger feasible to small wind energy conversion systems shown in the fig.(4). The wind turbine is connected to an axial flux PMSG which is rated at 6KW for the generated power, 10 poles & electrical frequency of

60HZ. The battery bank is composed by two lead-acid batteries, both rated at 12V/150Ah.

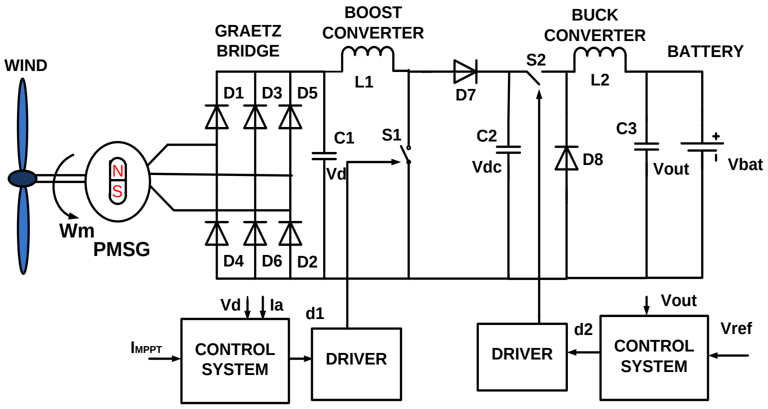


Fig .4 Proposed Battery charger

BOOST STAGE CONTROL:

The fig.5 shows the block diagram that represents the control system in the boost stage. The boost converter is driven through wind MPPT. There are many techniques generally adopted for extracting maximum power from wind turbine. This paper adopted a technique in which MPPT is achieved by measuring wind turbine rotor speed. The output voltage of Rectifier stage V_d and the inductor current I_a sets the feedback so that the boost converter is operated by the duty generated through the MPPT.

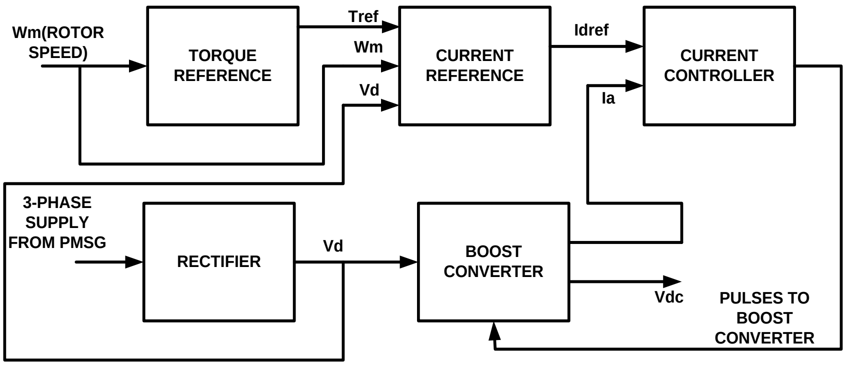


Fig 5 Control strategy for Boost converter

BUCK STAGE CONTROL

Voltage Mode Control: The voltage feedback arrangement is known as voltage-mode control when applied to dc-dc converters. Voltage-mode control (VMC) is widely used because it is easy to design and implement, and has good community to disturbances at the references input. VMC only contains single feedback loop from the output voltage.

The fig.6 shows the block diagram for control of buck converter. By using the controller, the duty cycle is adjusted to maintain the DC link voltage V_{dc} high and constant thereby ensuring correct interaction between boost and buck converters. A PWM block is used in this converter to generate pulses.

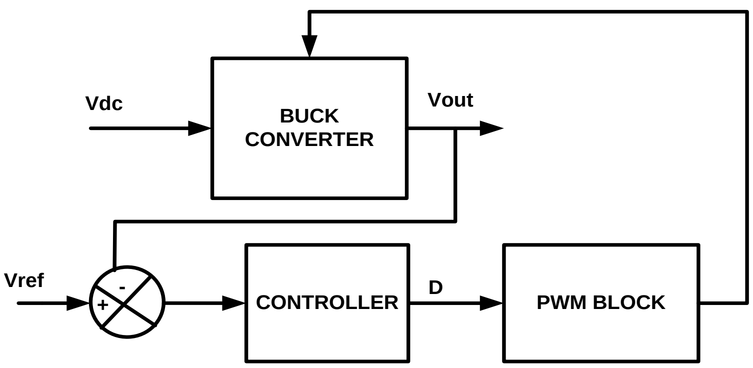


Fig 6.Voltage Control strategy for Buck converter

CONTROL OF THE WIND TURBINE

A mechanism to physically turn the blades around their longitudinal axes is used. At low wind speed a control system will use this feature to maximize energy extracted from the wind. During the higher wind speed the torque or power can easily be limited to its rated value by adjusting the pitch angle β. In addition the axial aerodynamics forces are reduced. This method is almost always used with variable speed turbines in order to make operation at high wind speed possible and safety. The turbine's electronic controller checks the power output constantly. When the power output becomes too high the blade pitch mechanism is asked to immediately turn the blades slightly out of the wind. When the wind speed is less strong the blades are turned back, into the most effective position. The complete system model of the pitch angle controller is shown in Fig.7.

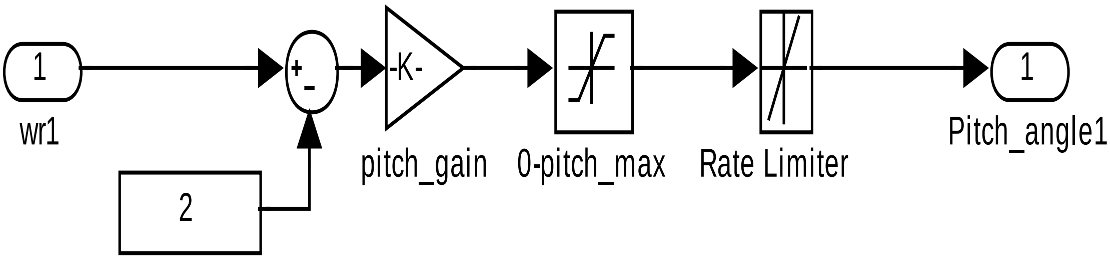
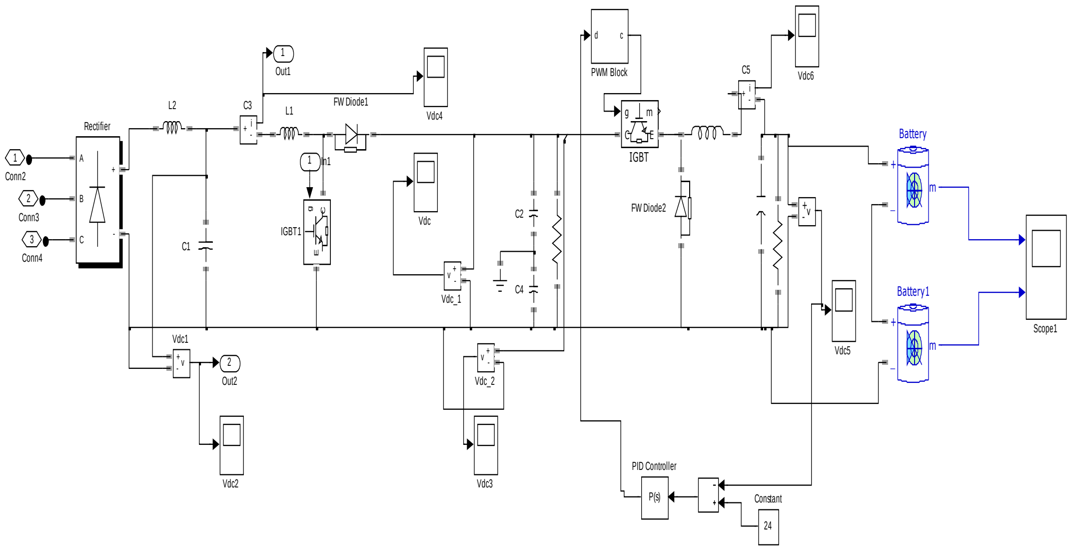


Fig 7 Pitch Angle Controller.

The control technique by means of which MPPT has been achieved in this project is Optimal Torque Control method.

IV. SIMULINK MODEL OF PROPOSED CONVERTER

The Simulink model of the power converters finally feeding batteries is shown below:



Boost and buck cascaded stage

Many control strategies can be used to get the desired voltage at buck level to feed the batteries. The control techniques used for buck converter in this topology are voltage control and sliding mode control. The ripples in the voltage controlled mode can be reduced by using the sliding mode current control also the performance achieved is satisfactory.

SIMULATION RESULTS

The rotor speed and the mechanical torque produced by the wind turbine are shown in the fig.8 and fig.9.

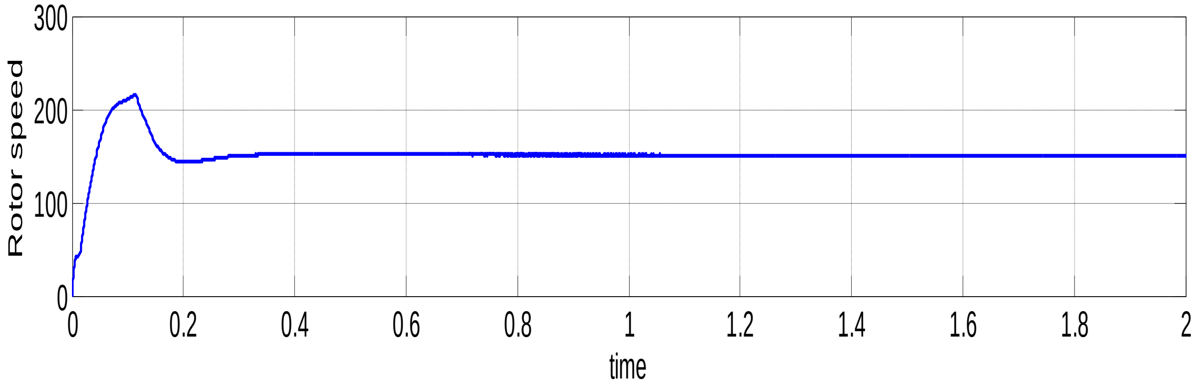


Fig. 8. Rotor speed of the wind turbine.

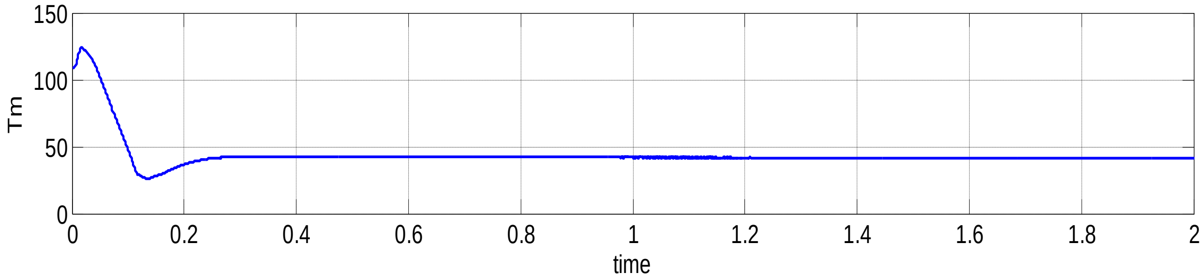


Fig. 9. Mechanical Torque of the wind turbine

The wind turbine is connected to the shaft which is further connected directly to PMSG as it is direct driven machine which needs no gear-box transmission system.

The electromagnetic torque generated by the Synchronous machine is shown in the fig.10.

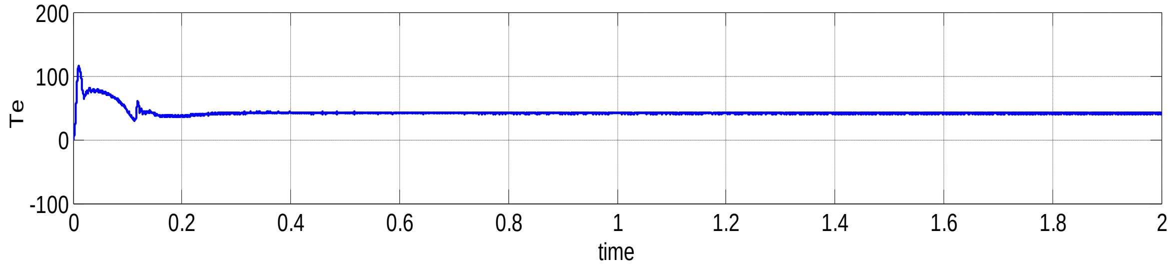
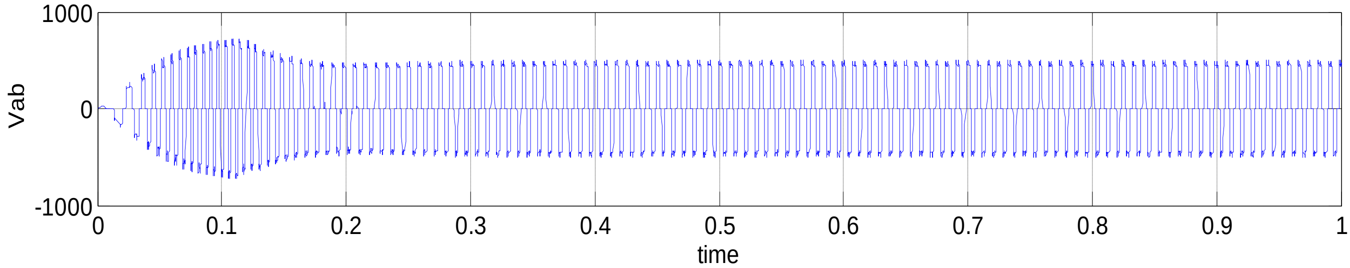
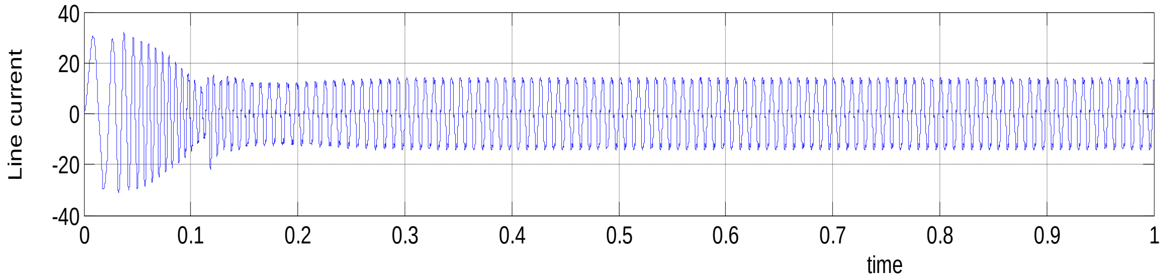


Fig.10. Electromagnetic torque.

The following figures gives the line values of voltage and current of the PMSG.



Line Voltage of the synchronous machine.



Line current obtained from the PMSG.

The Power obtained from PMSG is shown in the following fig.11

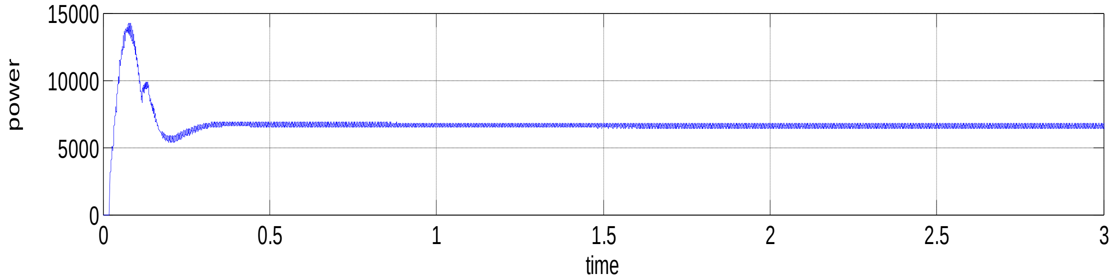
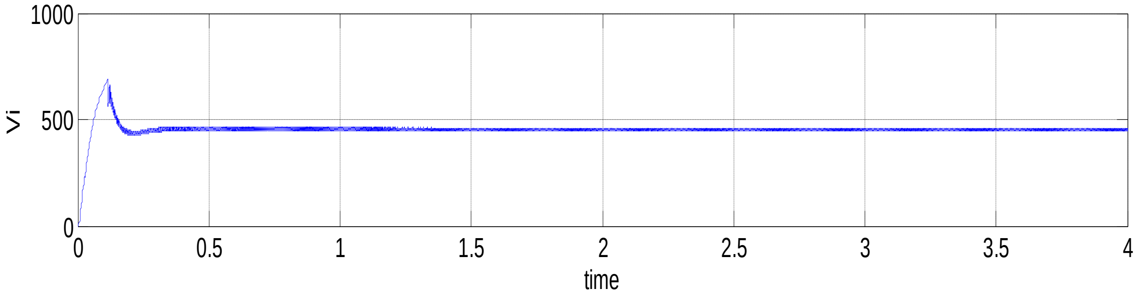
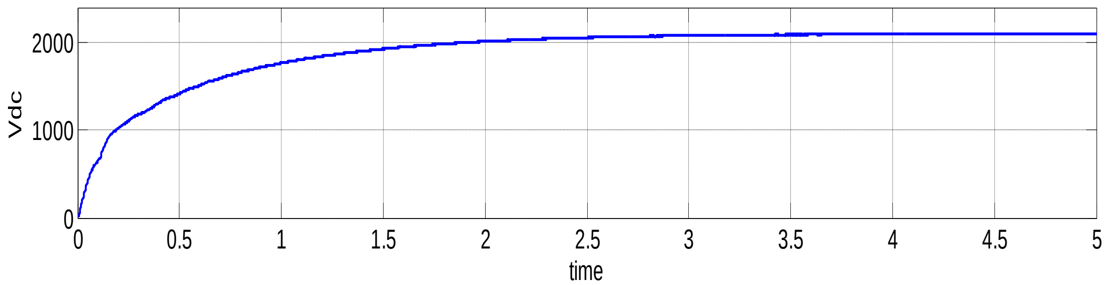


Fig.11. Power extracted from the PMSG

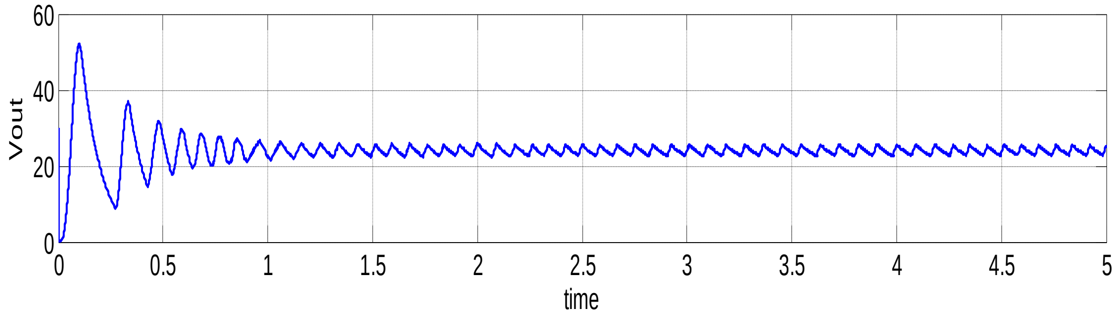
The following figure shows the rectified dc link voltage



Voltage waveform after rectifier stage

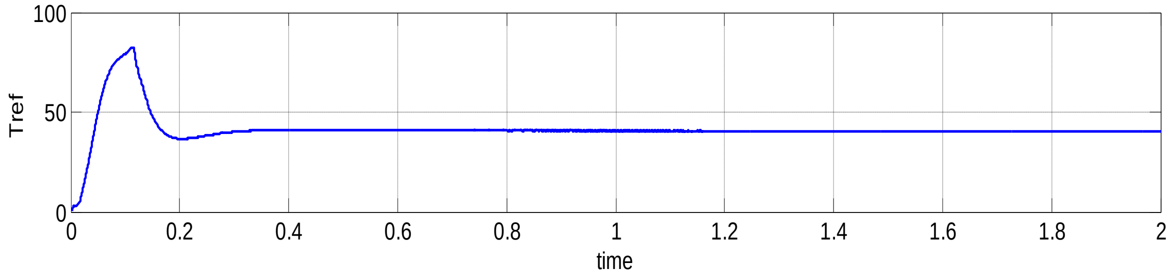


Boost converter output voltage waveform for maximum wind speed of 12m/s



Output voltage waveform after Buck stage

The MPPT technique used in this paper generates the following torque and current references.



Torque reference provided by MPPT

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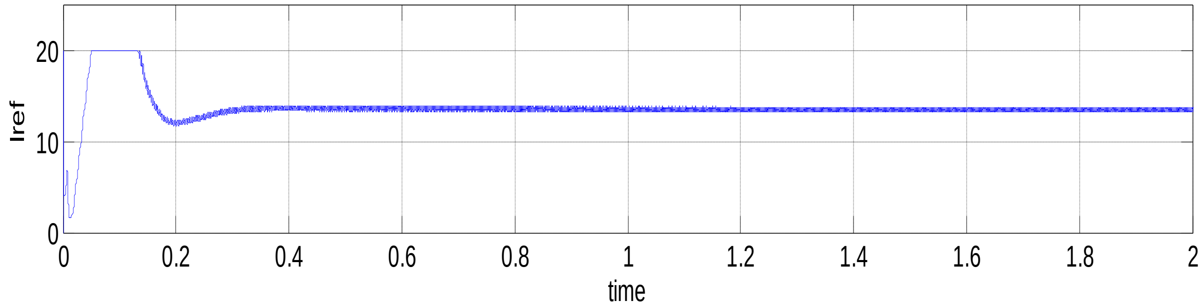
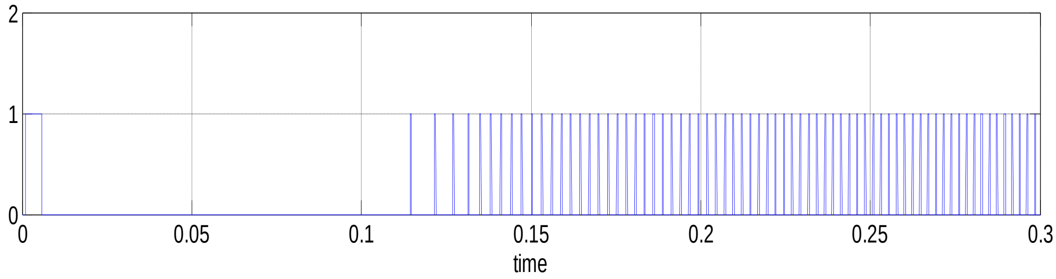
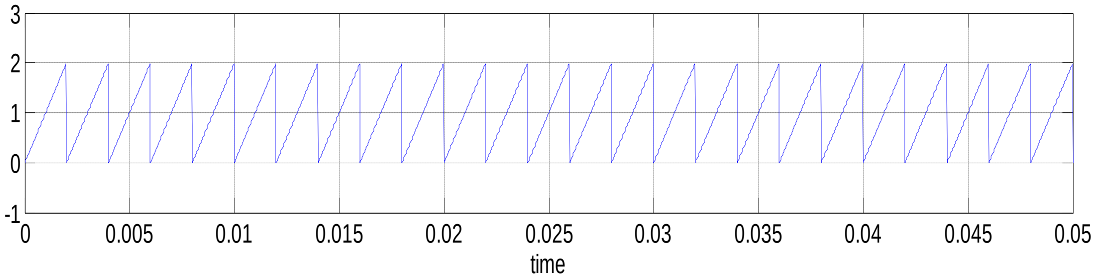


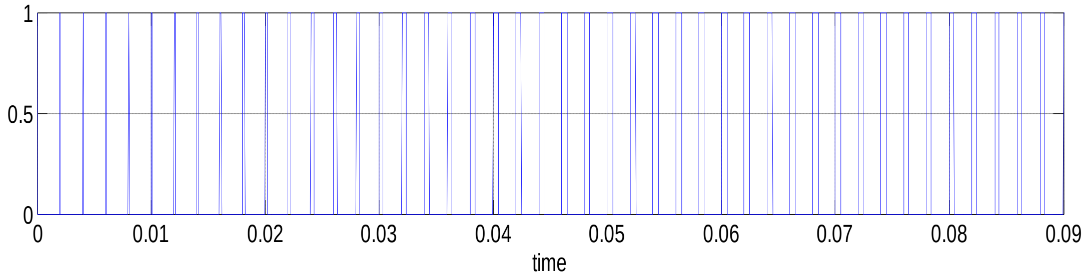
Current Reference provided by MPPT



Pulses given to boost switch to achieve MPPT

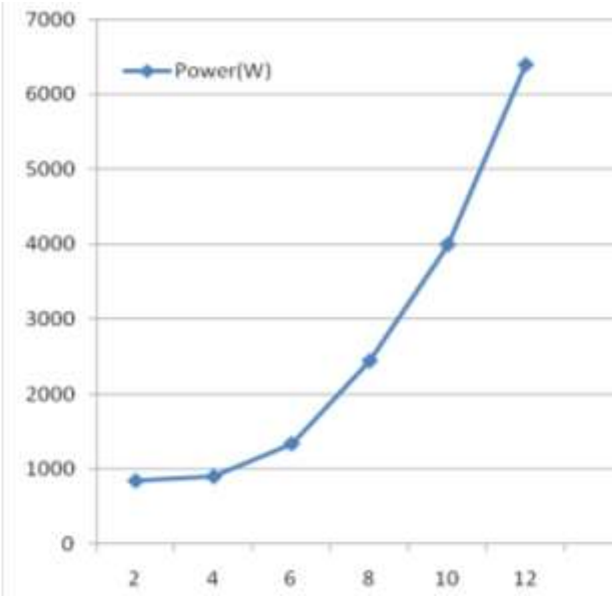


Repeating sequence used in PWM Modulator



Pulses from PWM Modulator

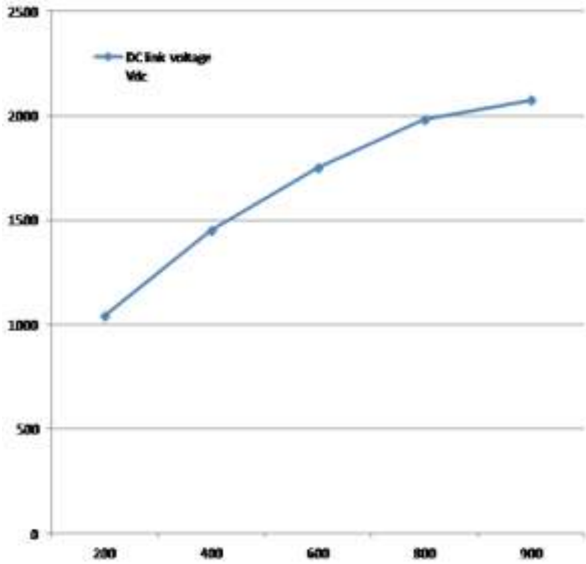
The following graph gives the Maximum Power Point operation for variable wind speeds. For a definite wind speed there will be a certain point where maximum power is extracted from the wind turbine. The points are plotted and MPP curve is drawn.



Wind speed (m/s)

Simulation result with MPP operation

The below graph shows the variation of the DC link voltage with the change in load (Ω).



Load Variation(Ω)

Variations in DC link voltage with change in load

V. CONCLUSIONS AND FUTURE SCOPE OF THE WORK

CONCLUSION

The modeling of a variable speed wind turbine with a permanent magnet synchronous generator has been developed and implemented in MATLAB/Simulink. This project has presented a three stage power converter as a battery charger feasible to small wind energy systems. The developed prototype is more efficient to transfer the maximum power from the wind turbine to the battery bank over the entire wind speed range and also in case where it is necessary to vary the number of connected batteries. In this project, maximum power point tracking concept has been presented in terms of the adoption of the generator speed according to instantaneous wind speed control strategies.

The control technique used for the buck converter is closed loop voltage control method and the MPPT used is Optimal Torque Control method.

FUTURE SCOPE

It is possible to implement this topology for small wind energy conversion systems where transmission of power is not possible. The advantage of this topology lies in the connection of desired number of batteries in series. The output voltage can be raised by connecting number of batteries in series depending upon the application.

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