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A Power Quality Improved Wind Energy Harvesting System For Standalone E Vehicle Battery Charging Applications

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Abstract– *The proposed battery charging method, which uses wind energy, is designed specifically for highway areas without access to the national grid, and its effectiveness has been shown in this study. The system under consideration is useful for charging stations located in remote places in highways and used for charging E vehicle batteries plying for long distances. This system design includes a permanent magnet synchronous generator (PMSG) that successfully absorbs wind energy and stores the harvested energy in a battery storage facility..The consumer's E vehicle battery can be charged from the station batteries. The station batteries are charged throughout the day, whenever wind with sufficient wind velocity is available. The proposed system uses a controlled Active front end three phase converter so that the current drawn from the PMSG is sinusoidal and The power factor remains at unity, independent of the frequency associated with the AC voltage output generated by the Permanent Magnet Synchronous Generator (PMSG)., which is a function of the speed of the PMSG. Maximum power point tracking is achieved using the sliding mode controller methodology, which integrates wind speed with turbine speed, estimated indirectly through PMSG voltage output..The proposed system, developed using the MATLAB SIMULINK framework, has been validated through simulation outcomes, confirming its effectiveness.*
Keywords– *Battery charging systems, Power electronic converters, E Vehicle, Hysteresis controllers, sliding mode controllers.*

1.INTRODUCTION

Numerous engineers and scientists worldwide are researching and developing renewable energy systems, with a particular focus on solar photovoltaic and wind energy conversion technologies. This scenario has emerged since the adverse effects of the global warming caused by the burning of fossil fuels for generating electrical energy had been observed since several years. The fast depletion of the fossil fuels and its unstable price due to international political conditions has also lead to the research on self sustainable renewable energy systems. The solar and wind energy systems are developed globally and the wind energy systems are used in tropical countries where the wind energy is available in abundance for a longer season of the year.A similar development that has associated with the management of global warming is the fast development in automobile industry. The traditional petrol diesel or gas powered engines for uses in automobiles are being slowly phased out and replaced by electric traction. This has triggered the developments in the related fields of special electrical machines, power electronic converters as drives for motors, power electronic based converters for charging the batteries as well as the development of high efficient highpower density batteries. The contemporary developments in the fields of power electronic semiconductors, the modern digital systems, and computer based graphics supported design, modeling and simulation systems have also helped to speed up the developments in the electrical vehicle industry as well as renewable energy harvesting systems.In this work a remote battery charging system, such of which can be deployed in highways where a battery charger may be helpful for long distance plying vehicles and the locations are far off from the national grid is proposed. The wind energy source has been identified as the source of energy as it can be operational through the day. The wind energy is harvested using a wind turbine PMSG system and then rectified by an active front end rectifier that charges a large battery called the station battery. The station battery may be used with additional power electronic converters to charge the customer vehicle batteries. The state of the art can be understood by considering some of the milestone contributions of other researchers in the fields of wind energy harvesting systems, power quality improvement techniques, real and reactive power compensation schemes and battery charging systems. Therefore, some of the important articles which have been published earlier have been considered for a review so as to grasp an insight into the available systems and schemes of power harvesting, conversion and dispensation.While using power electronic inverters for harvesting renewable energy sources it is possible that more than one inverters are used in the system for reasons like increasing power capacity, loading of optimum number of converters for at the optimal loading level so as to improve power conversion efficiency, interleaving for decreasing the voltage and current stress in power electronic devices and also for improving the quality of power on the source side and the load side A modified Power factor Corrected Rectifier supported by a proportional resonance controller has been proposed and validated in [1]. This system has used a STATCOM for reactive power support. The feasibility of employing a DSTATCOM to enhance reactive power support within a wind energy conversion system has been proposed and validated in existing research [2].A three phase grid connected inverter and the methodology of real andreactive power based reference signal generation and switching pulse generation are discussed in detail in [3].If the wind energy system can extend only real power to the grid more real power support can be extended to the loads by the grid. Meeting the reactive power demands of the load causes substantial issues for the grid. For reactive power support the consumers should provide their own arrangement. The transmission and distribution department also required reactive power for the operation of various power conversion systems like transformers. Therefore, the wind energySystems are now days expected to deliver real power as well as reactive power to the grid. Power quality management that includes unity power factor operation of systems, balancing of unbalanced load currents on the source side mitigation of harmonics are addressed by modern power conditioning equipment like the UPQC, the SAPF, DVR and the DSTACOM. Therefore, it is becoming a mandatory requirement that inverters are operated in parallel so that while one inverter is operating for real power the other inverter may be cooperated for reactive power support [4].A detailed discussion on the various methodologies and related issues of parallel operation of inverters has been presented in [5]. The FACTS devices and the custom power devices have been widely accepted as solutions for power quality related issues in power systems. The DSTATCOM and the Shunt Active Power Filter (SAPF) are used for reactive power support and mitigation of harmonics on the source current of nonlinear loads respectively [6]. Line impedance is a crucial factor in determining the performance of multiple inverters when linked in parallel on the AC side. The effect of line impedance on parallel inverters has been studied in [7]. A similar study on parallel inverters meant for real and reactive power support from each one of them have also been studied in [8].Wind and solar photo voltaic energy are the fairly reliable sources of renewable energy and the wind energy conversion systems are primarily used in tropical countries. The power coefficient of wind energy conversion systems is an important factor in determining their potential impact on energy output[9]. The integration of wind energy conversion systems can be improved by using static compensators like STATCOM, which are shunt-connected compensating equipment. A shunt compensator like the DSTACOM which can extend reactive power support is a case of parallel operation of inverters in systems which already use an inverter for real power support [10].The stepping up of voltage using DC to DC converters is required in case of energy harvesting systems where the primary form of electrical energy is DC like in the case of solar PV sources and The front-end rectifier is a critical component in wind energy conversion systems utilizing PMSG [11]. Usually in such converters the maximum power point tracking control is also included. While integrating power into the grid the integration process should pump into the system only real power. For this purpose, the at the point of integration the power factor is expected to be unity. A grid connected system that uses an inverter offering unity power factor on the integrating port has been demonstrated in [12].The optimal speed of wind turbines is critical for maximum energy capture for a given wind velocity, resulting in the highest power output in wind energy conversion systems. The MPPT algorithm optimizes wind energy conversion by selecting the turbine speed based on wind velocity, thereby requiring the use of a variable speed generator [13].In a related development as reported in [14] theauthors have developed a Wind energy systems that operate at varying speeds harvesting system using a speed sensor less method of optimum speed control based MPPT. There are many MPPT techniques for the different types of wind energy harvesting systems and a detailed comparative analysis of such MPPT techniques for This document described the wind energy gathering system [15].As for the integration of the energy from a PMSG to the grid, it requires a DC to DC converter at the front end followed by a DC link and an inverter. The AC output of the inverter can be integrated to the grid through appropriate passive filters for mitigation of harmonics caused by the switching of the power electronic switches. If a standalone nonlinear load is to be operated by the inverter, then we need additional power conditioning inverter that plays therole of a shunt active power filter as well as a DSTACOM.In this work a nonlinear load is to be connected to the PMSG directly. A battery charging system serves as a nonlinear load and is connected to the AC side of the PMSG. The proposed technology uses a PMSG with an active front-end rectifier to charge the battery, unlike existing systems that typically include a diode bridge rectifier. The active front end rectifier transforms the PMSG's AC output to DC, raises the voltage, and regulates the waveform to keep it sinusoidal and free of harmonics. The wind energy conversion system now includes a hysteresis controller capable of tracking maximum power points.

Following this introduction, section 2 defines the framework of the proposed system. Section 3 describes how to develop the suggested system using MATLAB SIMULINK. Section 4 presents an examination of the results. Finally, the conclusions and sources are offered.

2.OUTLINE OF THE PROPOSED WORK

Figure 1 illustrates the proposed concept, where the PMSG powers the AC side of the active front-end rectifier, while the DC bus bar is powered by the DC rails, coupled to a local DC load and a station battery. The station battery is charged and kept ready whenever wind with sufficient wind velocity is available. From the station battery the vehicle batteries may becharged.

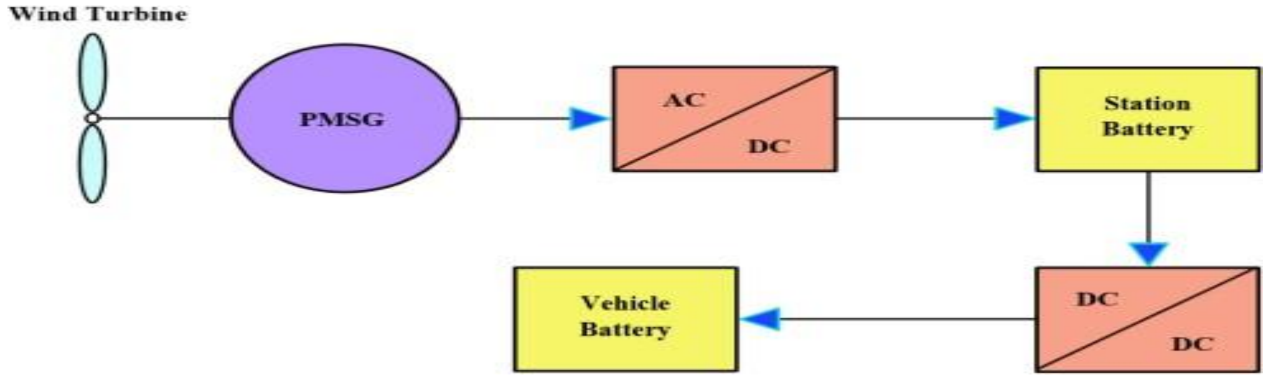

Figure1.Diagrammatic illustration of the work being proposed.

The proposed system uses a standalone wind velocity measuring system that uses a DC generator and the output voltage of this DC generator is calibrated and logged into the control system to represent the speed of the turbine. To optimize wind turbine energy capture, it is crucial to adjust its operational speed uniquely for each wind velocity To this effect a look up table is available for every wind turbine that tells the unique speed. The wind turbines actual speed can be determined by measuring the terminal voltage of the PMSG.

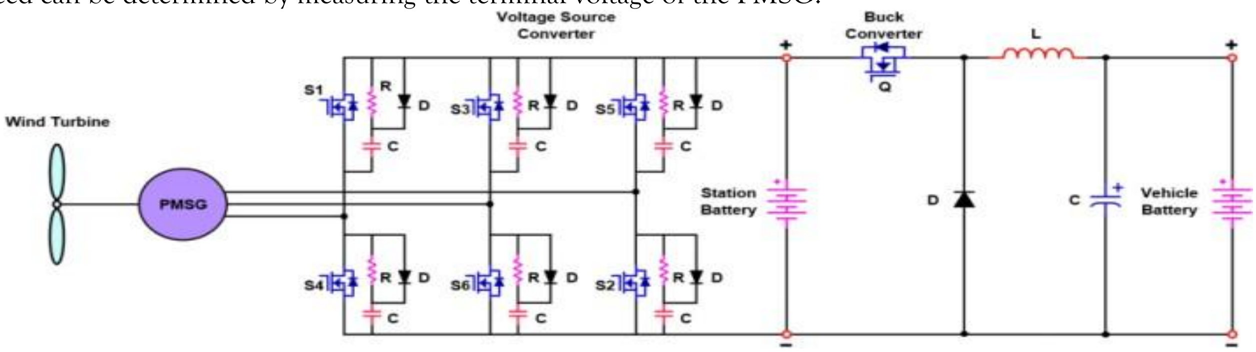

Figure2.Circuit topology of the proposed work

The kinetic energy contained in the blowing windby virtue of its velocity is converted into rotational form of mechanical energy in the wind turbine. The mechanical energy contained in the rotation of the turbine shaft is transmitted to the electrical generator which is of the Permanent Magnet Synchronous Generator (PMSG).

The energy produced by a wind turbine is determined by its sweep area and the cube of the wind speed, as per equation (1).

Windenergyharvested bythe turbine

$$= \frac{1}{2}\rho A V^3 \text{Joules}$$

Whereρisthewindvelocityand 'A' is an area swept by the wind turbine and Visthewind speed. The energy output of a wind turbine for different wind velocities and the corresponding speed of the turbine in per unit are related in the characteristics curve shown in figure 3.

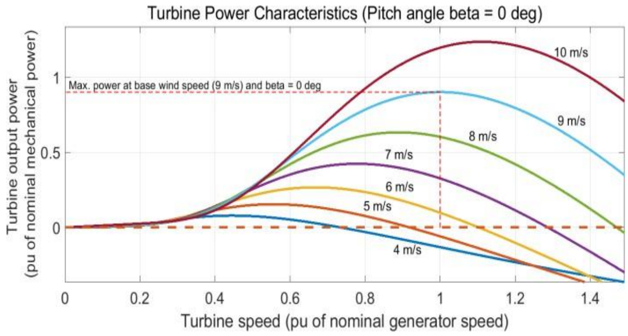

Figure3.Defining characteristics of wind turbines.

The energy obtained is a function of the wind velocity raised to the third power. Wind turbine energy reaches its maximum at a specific wind speed when the turbine's rotational speed corresponds to a unique singular value.A deviation of the speed of the turbine shaft from this unique speed will reduce the power harvested. This implies that a MPPT is essential for harvesting peak power from the wind turbine. Therefore, by the principle adopted in this work, the wind velocity is measured by an independent wind velocity sensor. The speed of wind observed is referred to a lookup table that gives the speed of the turbine for maximum power. If the load on the machine is higher than the speed of the turbine and the generator may fall down. Therefore, a controller that will adjust the power drawn from thegenerator can adjust the speed of the turbine system at the desired level. The changes in wind velocity is continuously monitored and the reference speed of the turbine is continuously updated

3. DYNAMIC MODELLING AND SIMULATION

Figure 4 illustrates the primary interface of the proposed system's MATLAB SIMULINK implementation. The main systems are the Wind turbine system, the PMSG, the active front end converter, the station battery, the buck converter system for charging the electric vehicle battery and the battery of the electrical vehicle are illustrated in the figure. The sub systems containing the control systems are presented in this section. The specifications of the proposed systems are given in table 1.

Table1. System Specifications

Wind turbine	
Rated Speed	3000RPM
Rated Power	12 KW
PMSG	
Rated Speed	3000RPM
Rated Power	10 KW
Type of Back EMF	Sinusoidal
Rectifier Type	Three Phase Active Front Boost Rectifier
Filter Series Inductor	25MilleHenry
Filter Shunt capacitor	100MFD
Station Battery capacity	30KAH
Station Battery Terminal Voltage	240V
EV Battery Capacity	120AH
EV Battery Voltage	48V

Control system for Active front End boost rectifier	PI with Hysteresis Controller
Control system for E V battery Charge Control	ConstantCurrent Sliding Mode Controller

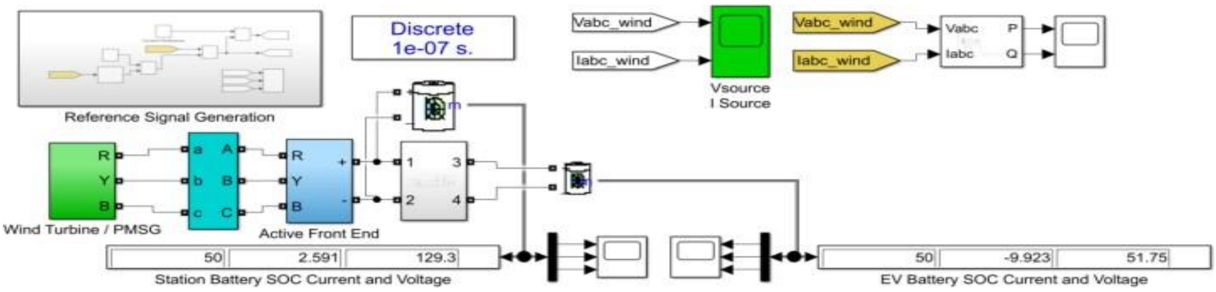

Figure4. Main Page of MATLAB SIMULINK Realization

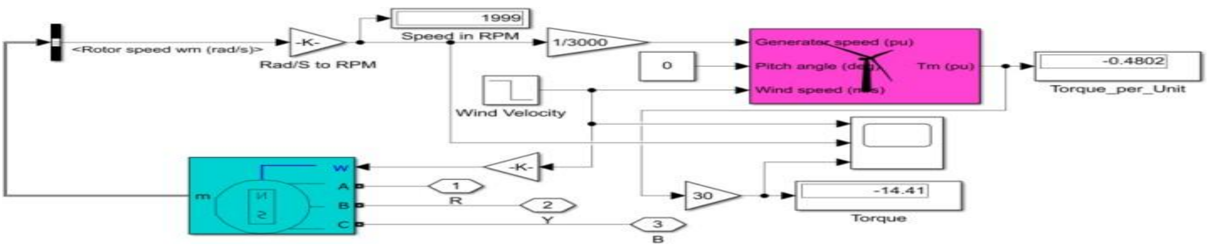

Figure5.The wind turbine and generator

The PMSG generates a three-phase AC voltage whose amplitude and frequency are determined by the generator's spinning speed.. The three phase AC output voltage is rectified by a three phase boost rectifier. In between the PMSG andthe three phase rectifier and inductor and a set of filter capacitors have been introduced. The topology of the three phase active front end rectifier is shown in figure 6.
The control associated with the three phase converter ensures rectification of the three phase voltage output of the PMSG and maintain the PMSG current sinusoidal. Besides the maximum power point tracking is also ensured by this converter. The wind turbine operates at its peak power at a specific speed that corresponds to the current wind velocity. If the electrical load on the PMSG is heavy then the speed of the PMSG falls belowthe optimum speed for MPPT. Ifthe electrical load on the PMSG is light then the speed of the turbine overshoots above the MPPT speed. A PI controller monitors the actual speed of the turbine and compares with the set point. The error is entered into the PI controller and thePIcontrollersgivesan output that is used as the amplitude for the reference signal used by the hysteresis controller for the active front end converter. The algorithm used for ensuring the maximum power point tracking is as follows.

- Measure wind velocity.
- Obtain the optimal speed from the look up table corresponding to the wind velocity.
- Measure actual turbine speed.
- Find error between set speed and actual speed.
- Use this error in a PI controller.
- The PI controller's output should be used to determine the amplitude of the reference sine wave that corresponds to the current of the PMSG.
- The hysteresis control method is applied to regulate both the actual current of the Permanent Magnet Synchronous Generator (PMSG) and the reference current.

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Figure 9 shows the realization of the control scheme for the active front end converter.

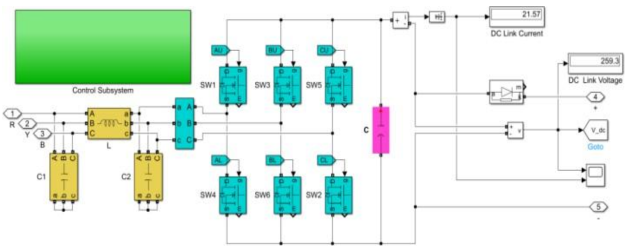

Figure6.The Three phase active front end converter

Figure 7 shows the reference signal generation scheme for the R phase. A zero crossing detector is used to route the switching pulses from the hysteresis comparator to the upper or lower switch of a leg. Three such controllers as shown in figure 8 are used for the three phases

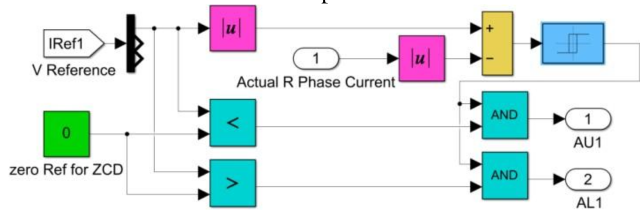

Figure7. Switching pulses generation for R phase Leg

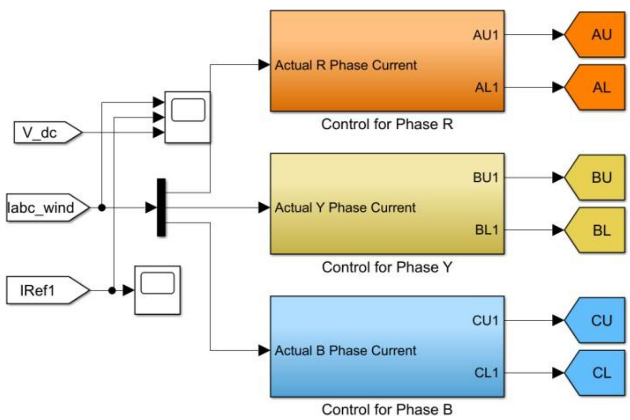

Figure 8: Switching pulse generation for the three phases

In order to get the reference signal a unit template signal is required. The unit template is a three phase sinusoidal signal of the same frequency and phase of the PMSG voltage. With reference to figure 9 the voltage output of the PMSG of a phase is used to gets its RMS value. Then the RMS is multiplied by 1.414. This gives the peak value ofthe PMSG voltage. If the peak value of the PMSG sign al is used to divide the PMSG voltage signal then the unit template is obtained. This unit templatehas amplitude of unity. This unity amplitude is then manipulated by theoutput of the (PI) controller generates the reference signal.

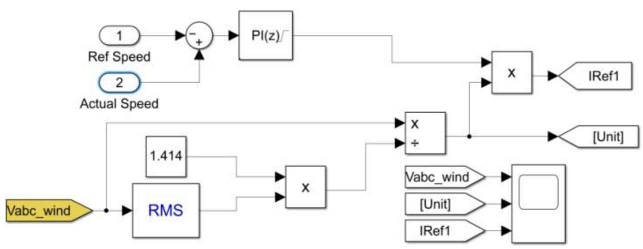

Figure9.Current Reference signal generation

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The control scheme for the charge controller for the EV battery as realized in MATLAB SIMULINK is shown in figure 10. The generation of switching pulses involves a comparator evaluating a triangular waveform with a constant duty cycle, set at 240 V and 48 V nominal EV battery voltage.Applying an input voltage of 240 V while maintaining a duty cycle of 0.5., according to the voltage gain equation V out = DutyCycle * Input voltage; can produce an output voltage of 120 V if the load is a resistor. However, the load is being a battery, and the battery being a voltage sink that does not allow large changes in the terminal voltage but can draw different current. The duty cycle of 0.5 drives a current through the battery. If the battery current is more than 10 amperes then the constraint flag isreset bya comparator that compares the difference between the battery's specified charging current and the current actually used to charge it. Thus, the battery charging current can be regulated at any desired value. The battery terminal voltage, a constant charging current and the SOC of the battery are presented in the results and discussions sections.

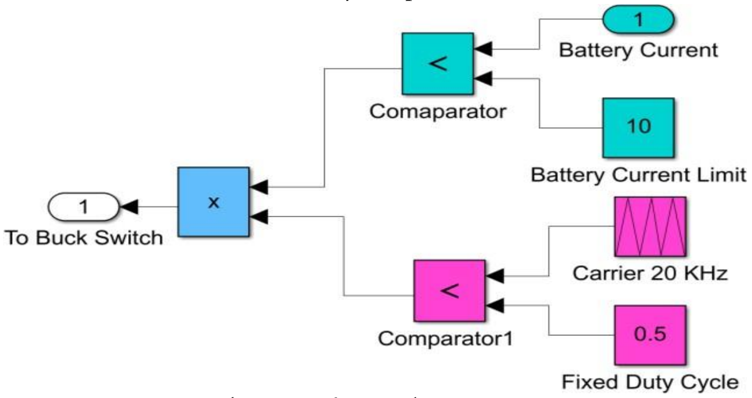


Figure10.Control system for EV battery

4.RESULTS AND DISCUSSION

Multiplying torque by rotational speed—which is impacted by wind velocity—determines the mechanical power produced by the turbine.The wind turbine generates mechanical energy which is then transferred to the generator shaft, ensuring that both shafts operate at the same rotational speed.High speed PMSG machines have lower number of pole pairs. Low speed PMSG machines use a large number of pole pairs and they rotate at a relatively slower speed. In this work a high speed PMSGwith4pairsofpoleshavebeen used. The step change in wind velocity that has caused the changes in the speed and torque has resulted in the change of electrical power delivered by the PMSG. The terminal voltage and the current supplied by the PMSG as shown in figure x shows the dependencies of the power delivered by the PMSG on the prevailing wind velocity and its change.With the model created in MATLAB SIMULINK a number of experiments were conducted. In one of the experiments, the proposed system has been tested with The wind velocity is significantly changed from 9 m/s to 6 m/s, and Figure 11 shows the changes in turbine speed and torque produced as a result.The specified wind speed is 9 m/s; for this wind velocity, the corresponding speed and torque are both represented as unit 1. The per unit speed corresponds to 3000 RPM and the torque for this wind velocity is 34 NM.The change in wind speed from 9 m/s to 6 m/s is in line with the wind turbine's operating parameters theexpected Per unit values ofspeed are torquerespectivelyare0.25and 0.65respectively. Theseper unit values correspond to a torque of 14 NM and a speed of 2000 RPM as shown in figure 11. The step change in the wind velocitycauses a changein theenergyharvested andis reflected in the PMSG voltage and current as exposed infigure 12.

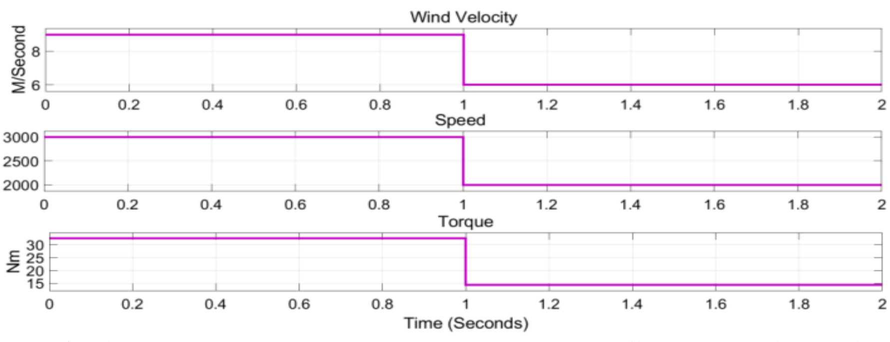


Figure 13 displays the station battery charging current as well as the DC link voltage.

Figure11.Variations in torque and Speed of the turbine with change in wind velocity

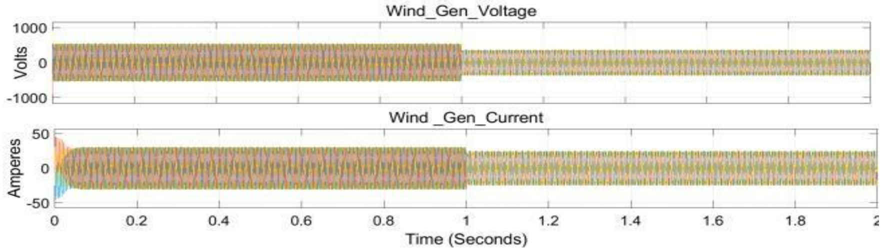


Figure12.Change in PMSG Voltage, Current and Frequency with change in wind velocity

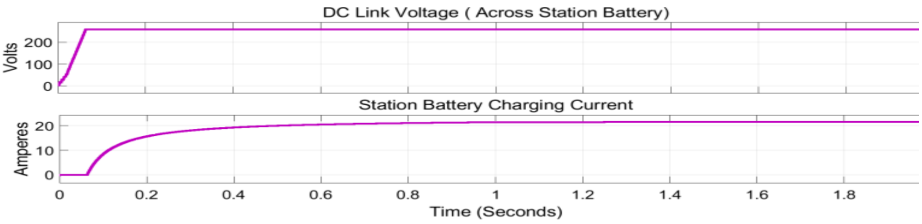


Figure13 The DC link k Voltage and Station battery charging current with a fixed wind velocity of 9 m/s.

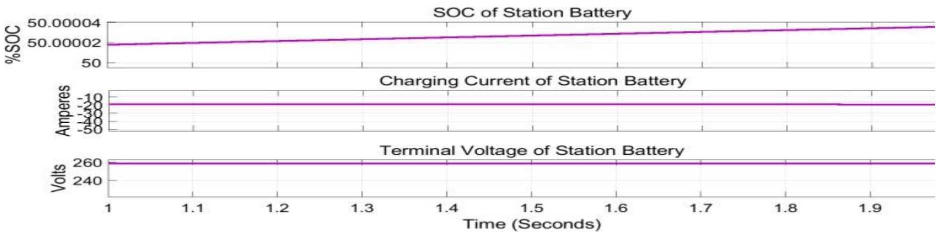


Figure 14 shows the increase in the State of Charge (SOC), charging current, and terminal voltage of the station battery.

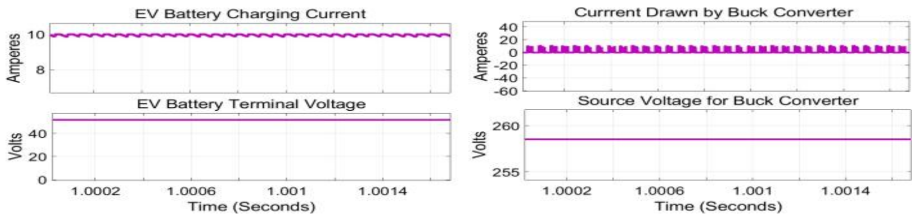
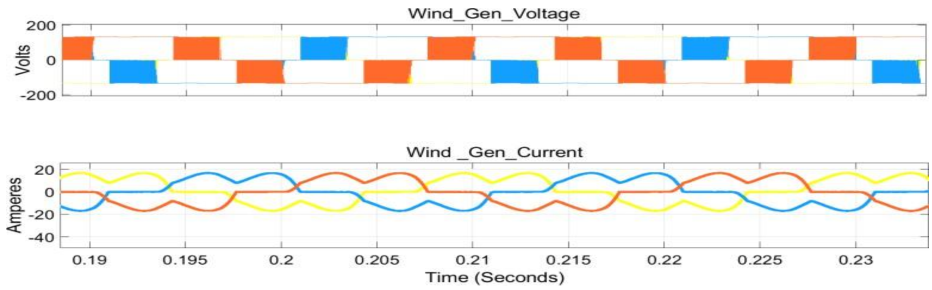


Figure 16. Waveforms associated with battery



While the battery is being charged, the terminal voltage of the battery, the battery charging current , the current drawn by buck converter from DC link and DC link Voltage are shown in figure 16.The advantage of the proposed system of active front end boost rectifier controlled by a hysteresis controller is that the source current, which is the PMSG current, becomes sinusoidal. In the conventional methods where a Diode Bridge Rectifier is used the PMSG current becomes highly nonlinear as shown in figure 17 and the FFT based source current spectrum is shown in figure 18, and the THD of the PMSG current is as high as 33.56% . With the proposed control scheme the PMSG current becomes sinusoidal and the THD of the PMSG current is 2,89% as shown in figures 19 and 20.

Figure17.PMSGcurrentwithDiodeBridgerectifier

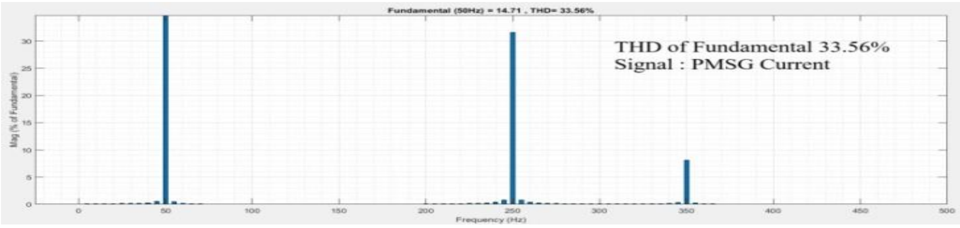


Figure18. FFT of the PMSG Current

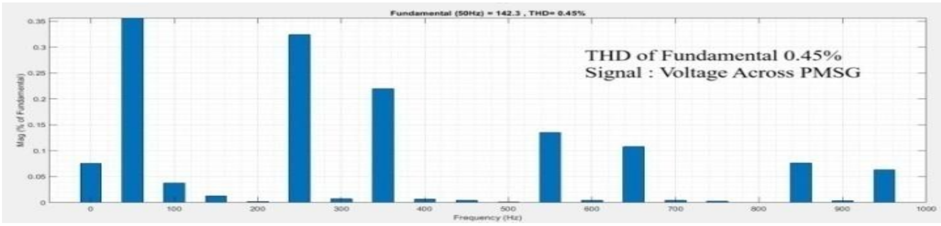


Figure19.FFT of the PMSG voltage with proposed controller

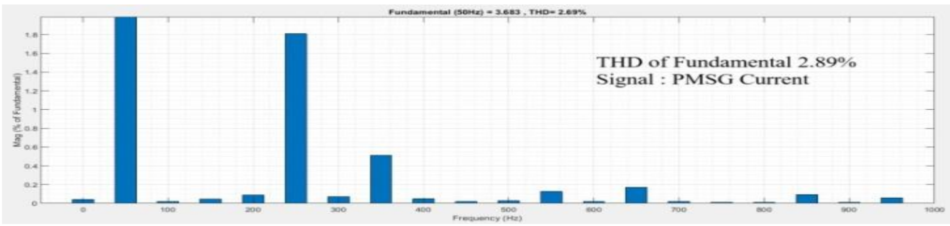


Figure20.Frequency spectrum of the PMSG current with proposed controller The key performance metrics at a wind velocity of 9 m/s are presented in Table 2.

Table2Comparisonofperformanceindices

TypesofConverter	PMSGVoltageTHD	PMSGCurrentTHD	EnergyHarvestingEffi	RippleinDCLink	SteadyStateErrorDCLi	CostandComplexity

			ciency		nkV	
WithDBR	44.32%	33.56%	68%	8V	3V	Less
ActiveFrontEndConverter	0.45%	2.89	78%	2.4V	0.9V	More

5. CONCLUSION

The wind energy conversion system, which utilizes an active front-end rectifier for battery charging and a Permanent Magnet Synchronous Generator (PMSG), has been successfully validated. The study suggests that using an active front end boost rectifier can eliminate the need for a traditional front end diode bridge rectifier and DC to DC boost converter. Further the diode bridge rectifier based system draws nonlinear current from the PMSG. The proposed system has proved to draw sinusoidal current from the PMSGfor differentspeedscorrespondingtowindvelocities. The Battery charging system consists of a station battery charged from the active front end boost rectifier and a buck converter powered from the station battery. The efficiency of the suggested method in the system under discussion has been demonstrated by its successful implementation using MATLAB SIMULINK.

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