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New Generation PV Powered Country Boat Using Buck-Boost Chopper and PWM for Green Sailing

Soumya Das[1]*, Pradip Kumar Sadhu [2], Suprava Chakraborty [2], Akanksha Ranjan[2], Monika Yadav[2]

[1]*Department of Electrical Engineering, University Institute of Technology, Burdwan University, WB-713104, India*

[2]*Electrical Engineering Department, Indian School of Mines (under MHRD, Govt. of India), Dhanbad- 826004, India*

***Corresponding Author's E-mail:** soumya.sd1984@gmail.com*

Abstract

This paper presents a country boat for green sailing utilizing the application of stand-alone photovoltaic system using Buck-Boost chopper and PWM inverter which simplifies the power system and stabilize the economic factor. From the viewpoint of environmental protection it is very much essential to regulate the amount of exhaust gases emitted from the diesel engines which are used in the normal country boat for sailing in short or long distances. In general, nitrogen oxide, sulphur oxide and particulate matters are considered as toxic substances in exhaust gas from diesel engines, as it causes several fatal diseases. Hence a green sailing country boat, which is solar photo voltaic powered is an alternative solution of diesel engine fitted country boat. Performance and control of DC-DC chopper and PWM inverter are essential in PV applications. The chopper and inverter used here are Buck-Boost chopper and PWM inverter respectively, which feed an AC single phase induction motor load. The PV panel, Buck-Boost chopper, PWM inverter and single phase induction motor are modeled using Sim-Power System blocks in MATLAB/SIMULINK environment.

Keywords: *PV, Country Boat, Buck-Boost Chopper, PWM Inverter, Green Sailing, MATLAB/SIMULINK.*

1. Introduction

Transport in waterways used to be the main source of communication back in ancient days and is still definitely one of the most reliable life sustenance features of the modern society; practically fossil fuels provides all the required energy, but it creates heavy ecological problems in all large cities. The main solution of these problems is the proper use of the renewable energy sources, and there are many credible examples of this kind, like a solar powered country boat which uses only solar energy converted by Photo Voltaic Converters (PVCs) and feeding an AC load [1] [23]. It is of utmost importance to generate a pollution-free, Eco friendly and clean energy. Electricity generated from photovoltaic (PV) power systems is one of the major renewable energy sources which involves almost zero greenhouse gas emission and doesn't consume any fossil fuel [2] [3] [4]. In general, nitrogen oxide (NO_x), sulfur oxide (SO_x) and particulate matters (PM) are considered as toxic substances in exhaust gas from diesel engines, as it causes several fatal diseases like lung cancer, bronchial asthma, hay fever, etc. Hence a green sailing country boat, which is solar photo voltaic powered is an alternative solution of diesel engine fitted country boat. Solar energy created from Photovoltaic cells is an efficient source of energy: it is renewable, inexhaustible and pollution free, for this, the use of solar energy is increasing rapidly in recent years. Although the PV modules were very expensive and the energy con-version efficiency was relatively low, but they have become

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cheaper during the last decade due to the developments of manufacturing techniques [5]. In standalone photovoltaic generator (PVG), the generated energy is used either directly or associated with a storage in battery or with an energy reserve, e.g. hydraulic. In connected PVG, it may be associated with inverters and choppers. A PVG with good efficiency can be carried out if it constantly converts maximum available solar power all the time, even in case of a rainy day [6]. The chopper and inverter used here are Buck-Boost chopper and PWM inverter respectively, which feed an AC single phase induction motor load. [7] [8] [9].

2. Proposed PV Powered Country Boat

PV with Electric propulsion has got many advantages like silent and smooth running of the boats, reduced need for maintenance, autonomous electric sailing, less emissions of CO_2 and volatile organic compounds (VOCs) and access to waters which are prohibited for boats with combustion engines Therefore proper attention should be given to the topic of implementing PV into boats. Use of Solar PV instead of fossil fuel based boat will help to survive sea-grass. Sea grasses are plants living in underwater, helps in aiding other marine life and preserving the natural hydrology. One of the primary problems of electric propulsion and boats is that really high quantity of electrical energy is required to get to a certain velocity. Efficiency in the electrical system together with low boat weight plays a pivotal role to achieve higher boat speeds. Recent research has dealt with most of the DC/DC chopper in order to find the most compatible type in terms of overall power system efficiency. Schematic diagram of proposed photovoltaic powered country boat with Buck-Boost chopper and PWM inverter feeds a single phase induction motor load is shown in Figure 1. Solar energy conversion into electrical power is naturally performed by solar cells [10] [11]. The PV generator transfers the descendent solar radiation to a direct voltage and current. These ends provide a Buck-Boost chopper and a PWM inverter. The load of inverter is the single phase induction motor [12].

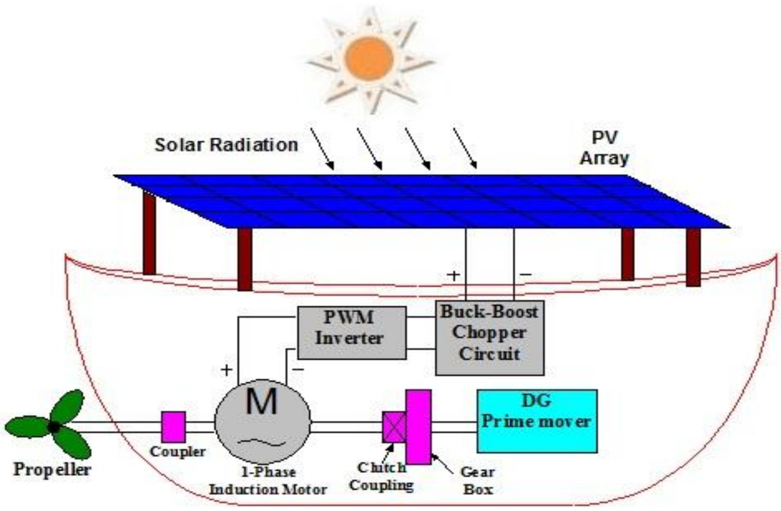

Figure 1: Schematic Diagram of PV powered Sailing Boat

Earlier proposed DC motor based country boat schemes are suitable for non-saline atmosphere. But sea sailing boats are facing trouble of NaCl deposition on the electrical component of the motor. In earlier schemes DC motor was used which has a commutator component. Commentator segment of the DC motor will be affected by the deposition of NaCl, present in the sea water that will cause short circuit of the segment. Even if the NaCl deposition layer will be removed from the maintenance team, then again within a short span of time redisposition will occur. NaCl deposition problem in commutator segment is not there for Induction motor drives. Induction motor drives are more reliable for sea sailing boats, whereas DC motor drives are suitable for river country boat. Solar panels are rarely connected to the electrical equipment directly, except grid connected system. Power generated from the solar panel depends on the strength of the sunlight. Buck-boost chopper is providing the necessary supply on the sunny day as well as cloudy days. Chopper is employed in buck mode when very high power voltage is generated from the PV array, and when the voltage is on the lower side chopper works in boost mode to boost up the voltage at a specific value. The output of the motor also connected to a propeller through a coupler. On the other hand another side of the motor shaft is connected with a diesel generator (DG) prime mover through another clutch coupler. At night time when solar PV does not generate the necessary power, then pressing the coupler this DG prime mover is connected with the motor shaft. Moreover, this DG generator is connected as a backup protection. Cost competitive cover design with fluorides in place of glass is to be good alternatives when considering cost and weight reduction of PV modules [13]. If the entire weight of a boat is lower, the energy is desired reasonably less [14] [24]. Additionally, the PV panel provides the necessary shedding to the passengers by boat from the direct sunlight and also from the rain.

2.1. Buck-Boost converter analysis

One of the most important types of switching regulators is the buck-boost converter. In this converter, the features of buck and boost are combined into one. A buck-boost converter consists of a diode, an input voltage source, an inductor, a capacitor, and the load, which represents output voltage. A switch is connected between the input and the inductor, and the diode is placed between the inductor and the load capacitor in a reverse direction, as shown in Figure 2. For power conversion in the converter only one inductor is sufficient. The buck-boost converter provides an output voltage that may be less than or greater than the input voltage. In this case buck-boost converter is used for PV powered country boat system which requires 110 V at the output end.

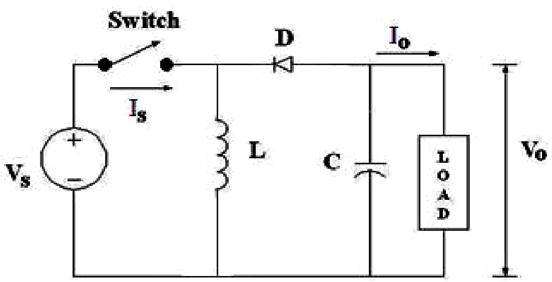

Figure 2: Basic buck-boost chopper circuit

The duty ratio of chopper (α) is given by equation (1) and the chopping ratio (Y) is given by the relation (2) and (3), with t_1 is the on-time of the chopper switch (S) and T_1 is the switching period of the chopper switch (S) [12] [22].

$$\alpha = \frac{t_1}{T_1} \tag{1}$$

$$\frac{V_O}{V} = \frac{\alpha}{1-\alpha} \tag{2}$$

Where V_O is the voltage across load and V is supply voltage of converter.

$$Y = \frac{\alpha}{1-\alpha} \tag{3}$$

According to IEC harmonics standard, Current ripple factor should be bounded within 30% is given by equation (4) and the voltage ripple factor should be bounded within 5% is given by equation (5).

$$\frac{\Delta I}{I} = 30\% \tag{4}$$

$$\frac{\Delta V_O}{V_O} = 5\% \tag{5}$$

Where ΔI is the ripple current and I is the output current of the chopper and ΔV_O is the ripple voltage. Inductor (L) and capacitor (C) are given by equation (6) and (7) respectively with frequency (f) and load resistance (R)

$$L = \frac{V \times \alpha}{f \times \Delta I} \tag{6}$$

$$C = \frac{\alpha}{f \times R \times \left(\frac{\Delta V_O}{V_O}\right)} \tag{7}$$

2.2. PWM inverter analysis

The most common and popular technique for generating True sine Wave is Pulse Width Modulation (PWM). Sinusoidal Pulse Width Modulation is the best technique for this. This PWM technique involves generation of a digital waveform, for which the duty cycle can be modulated in such a way so that the average voltage waveform corresponds to a pure sine wave. The simplest way of producing the SPWM signal is through comparing a low power sine wave reference with a high frequency triangular wave. The basic PWM circuit shown in Figure 3.

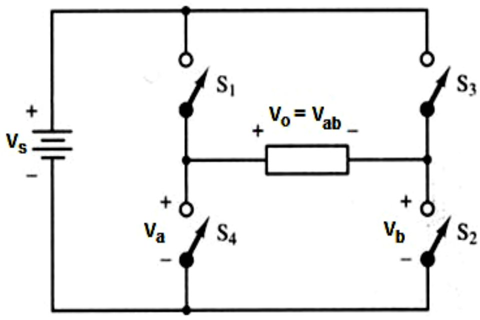

Figure 3: Basic PWM circuit

The rms ac output voltage

$$V_O = V_s\sqrt{\frac{p\delta}{\pi}} \rightarrow V_s\sqrt{\sum_{m=1}^{2p}\frac{\delta_m}{\pi}} \tag{8}$$

Where p=number of pulses and δ= pulse width

3. Matlab-Simulink Environment

Usually it has been seen that a single 1.5 HP single phase induction motor is sufficient for carrying 4 passengers weighing approximately 350 kg in a PV powered country boat and if the converter efficiency is considered as 94% approximately then, input of the chopper is 1186 Watt. Also input of the chopper is the output of the PV panels. If a single PV panel is producing 300 watt, so four numbers of panels are required. Modeling of total system, including subsystems is shown in Figure 4.

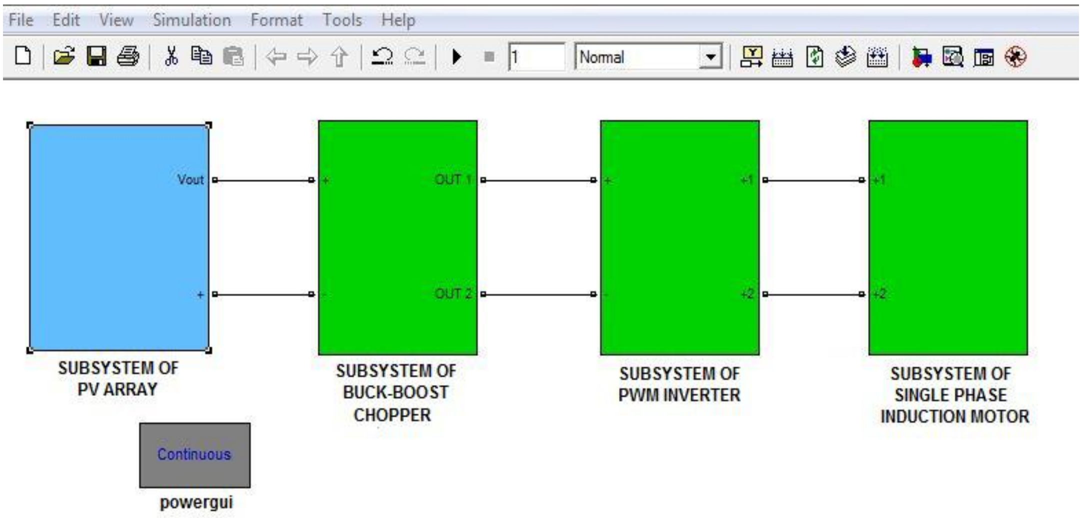

Figure 4: Simulink model of proposed system

3.1. Modeling of the PV array

In Figure 5 the model of PV panel acting as a constant DC source is created using the subsystem blocks from Simulink library browser. Here in the Matlab simulation of a PV module the parameters of the solar cells are being taken as 300-watt Module. The open circuit voltage (V_{OC}) of the module is 44.72volt. As 72 solar cells are connected in series so the individual voltage of a solar cell is 44.72/72=0.62volt. In subsystem blocks, Six solar cells are connected in series first, then they are masked into a subsystem & three in a series are added to make it 18 and then two subsystems of 18 are connected in series to make 36. Then two subsystems of 36 are connected to make it a module of 72 solar cells and finally 4 PV modules are connected in series [15-21] [25]. The solar insolation is taken as 1000w/m^2. For getting maximum power voltage and maximum power current the value of load resistance should be (V_m / I_m) 17.53Ω. Specification of a single PV module is given in Table 1.

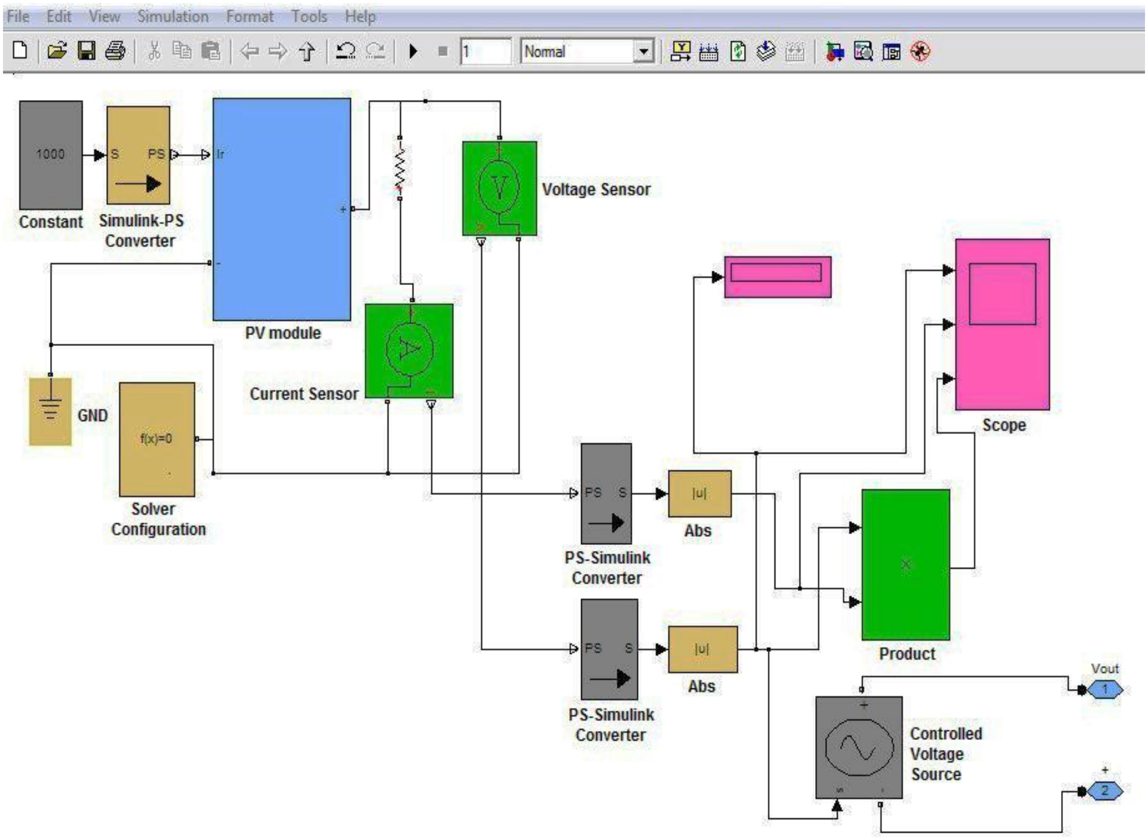

Figure 5: SIMULINK model of PV module

Table 1: Specification of Single PV module

No. of cells per Module	Maximum Power in watt	Open Circuit Voltage (V_{oc}) in Volt	Short Circuit Current (I_{sc}) in Amp	Maximum Power Voltage in Volt	Maximum Power Current in Amp	Weight in Kg (Aprox)	Dimensions (Length × Width × Depth) (Aprox)
72	300	44.72	8.62	35.86	8.18	23	77 mm× 39 mm× 1.5 mm

3.2. Modeling of buck-boost chopper

Figure 6 presents a SIMULINK diagram of a buck-boost chopper. Where the output voltage of the converter is taken to be 110 Volt. For buck mode input voltage of chopper is taken as 144 Volt while for boost mode input voltage is 60 Volt.

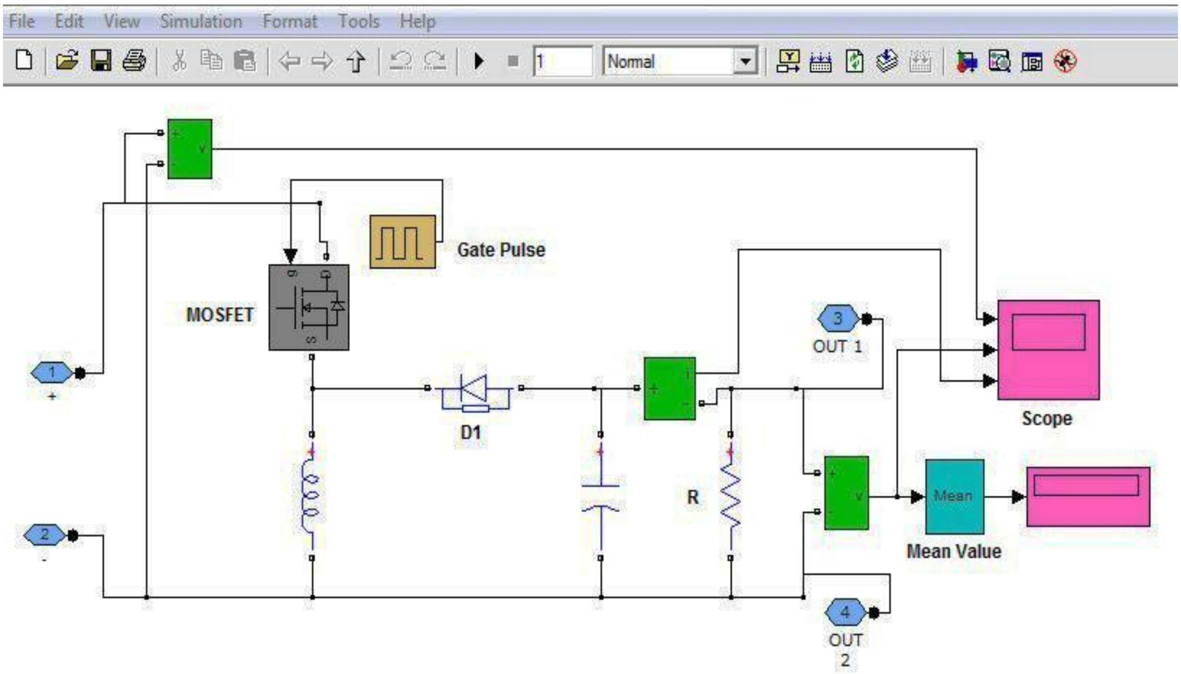

Figure 6: SIMULINK model of buck-boost chopper

3.3. Modeling of PWM inverter

Figure 7 presents a SIMULINK diagram of a PWM inverter. Where the output voltage of the inverter is 110 Volt AC.

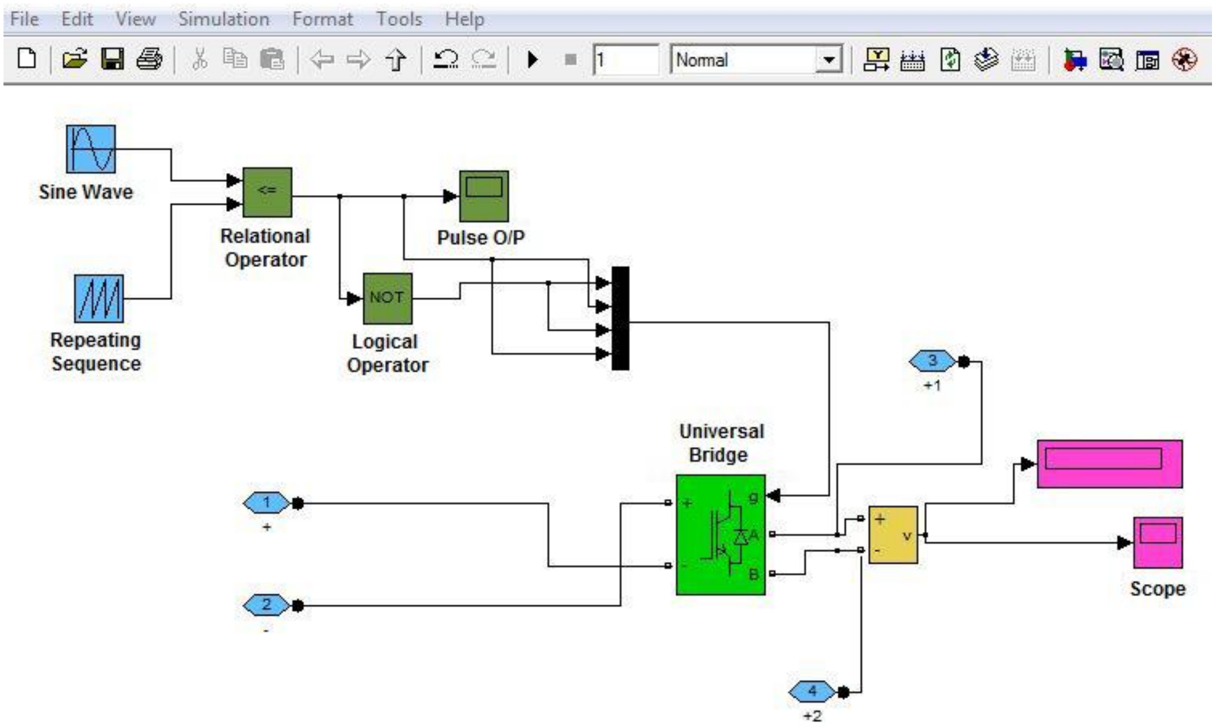

Figure 7: SIMULINK model of PWM inverter

3.4. Modeling of single phase induction motor

Figure 8 presents a SIMULINK diagram of a single phase induction motor. Where the input voltage and power of the motor is taken to be 110 Volt AC and 1.5HP respectively.

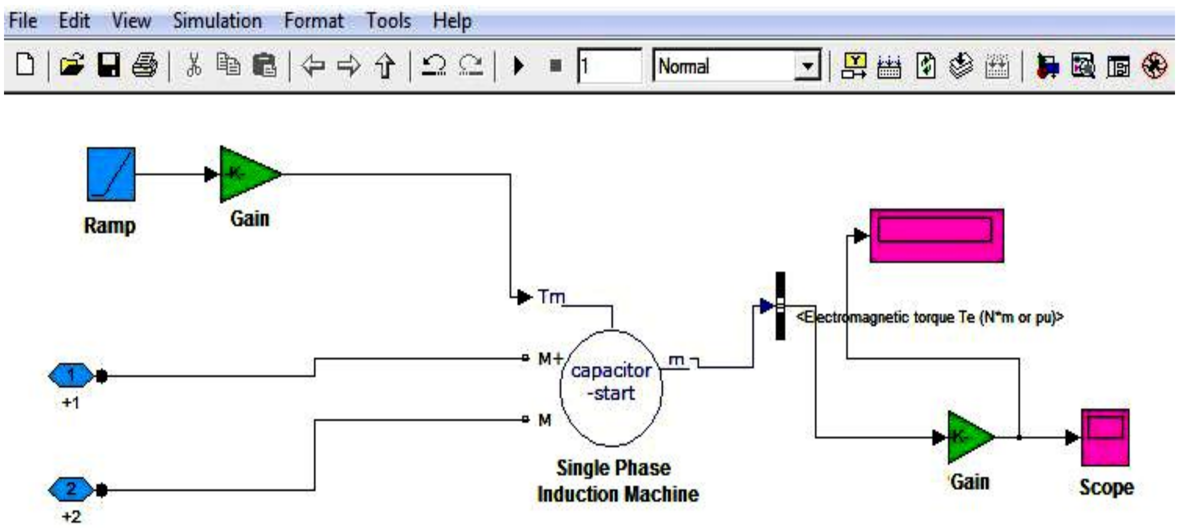

Figure 8: SIMULINK model of single phase induction motor

4. Result and Simulation

The models shown in the above figures were simulated using MATLAB / SIMULINK. Simulation and results for PV module and buck-boost chopper and PWM inverter have been recorded to make sure that the circuit can be obtained accurately. The voltage, current and output power is the main points to take into account. The complexity and simplicity of the circuit have been set based on the literature. Figure 9 shows a SIMULINK result of the PV array. In the simulation graph of the PV array, maximum output voltage and maximum output current and maximum power are 144 volt, 8.25 Amp and 1186 Watt respectively.

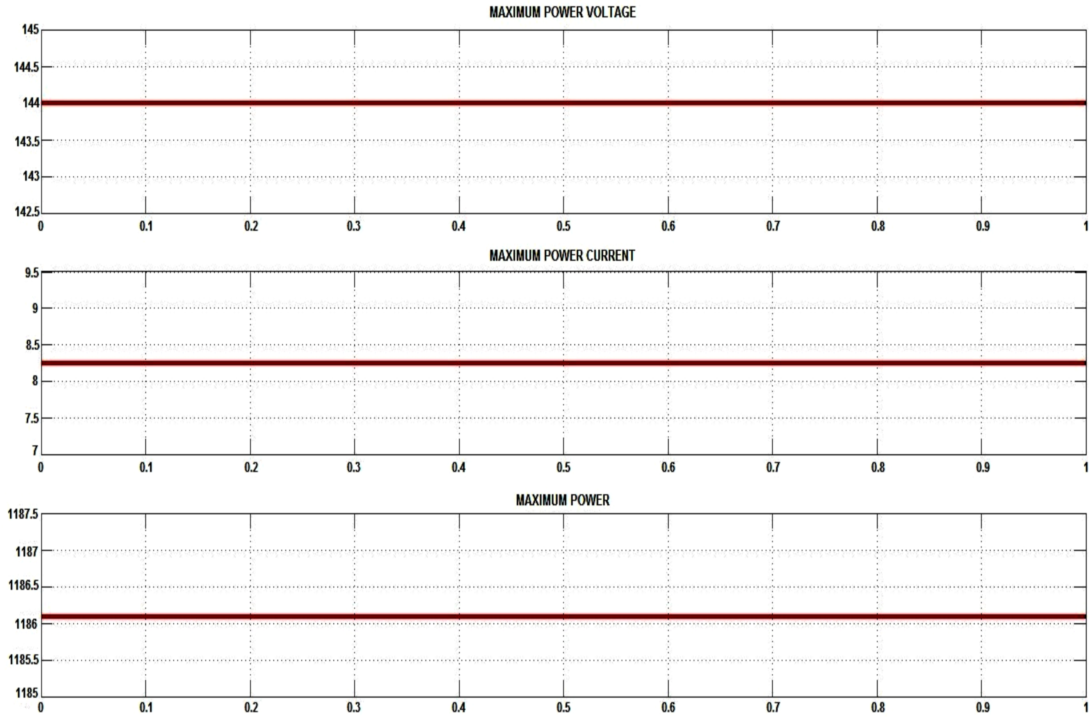

Figure 9: Output voltage, current and power of PV panel module

Figure 10 shows a SIMULINK result of buck-boost converter when converter operating in buck mode. In this simulation graph input of the converter is 144 volt, which is the output of the PV array and converter step-down this voltage of -110 volt.

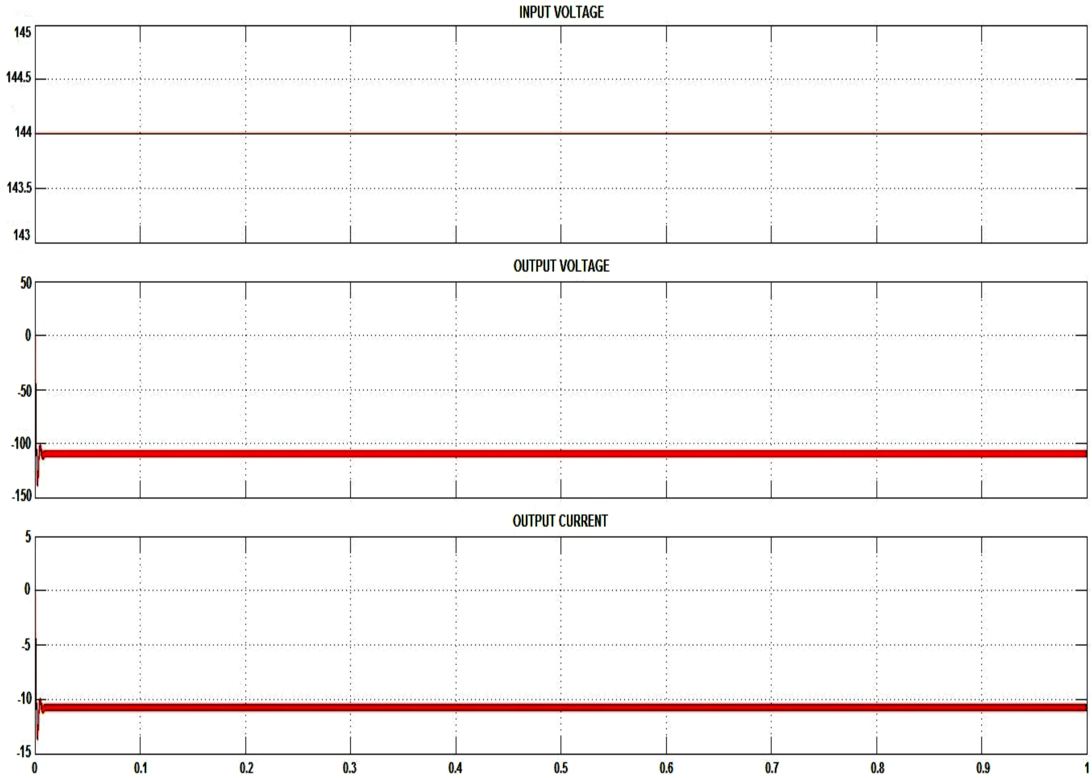

Figure 10: Input voltage, output voltage and current of buck-boost converter for buck mode operation

Similarly, Figure 11 shows a SIMULINK result of PV array with buck-boost converter when converter operating on boost mode. In this simulation graph input of the converter is 60 volt, which is the output of the PV array and converter step-up this voltage of -110 volt.

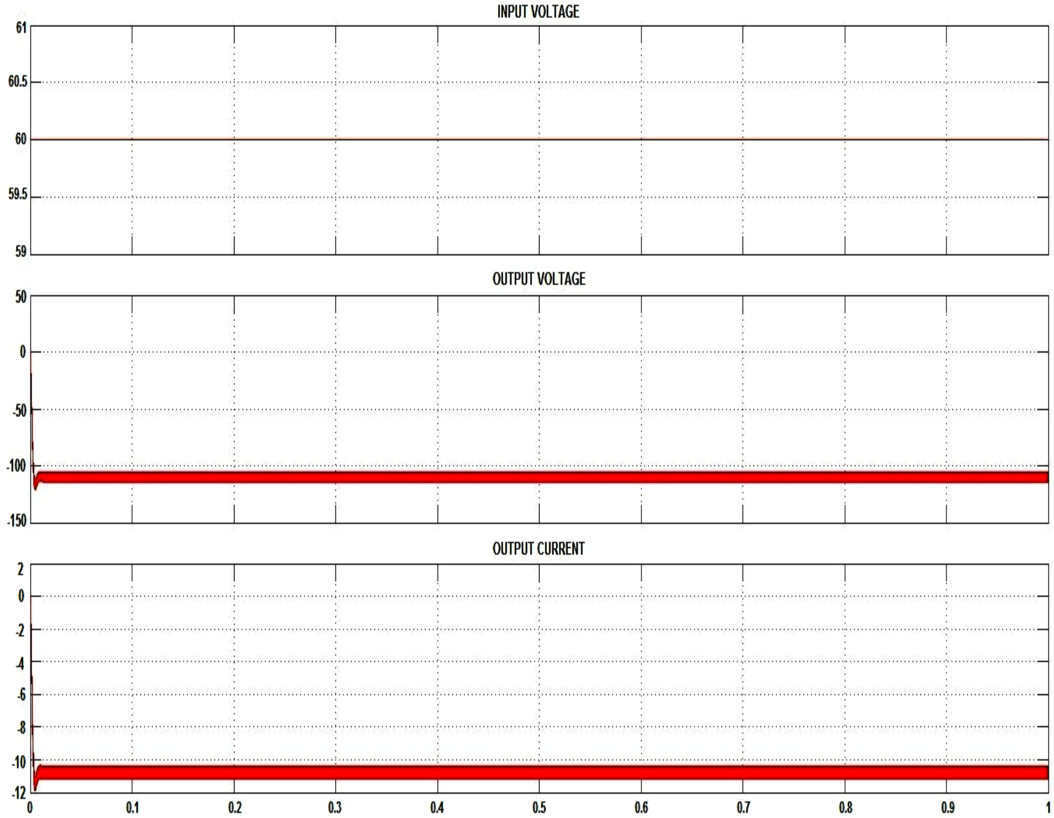

Figure 11: Input voltage, output voltage and current of buck-boost converter for boost mode operation

The buck-boost converter produces a negative voltage with respect to the input. That is why in the simulation graph output voltage is -110 for both buck and boost mode. All the experimental values are same as with the theoretical ones. Figure 12 shows the inverter output of 110 Volt. The gating signals are generated by comparing a sinusoidal reference with a high frequency triangular signal. This inverter output is fed to the induction motor to drive the sea sailing boat.

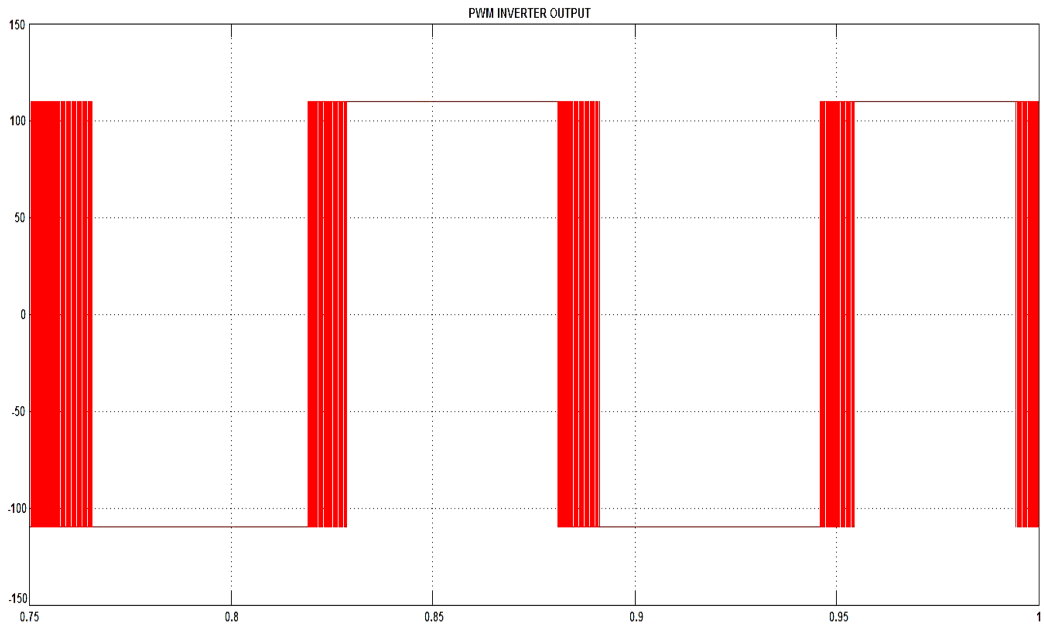

Figure 12: Output voltage of PWM inverter

The output torque curve of an induction motor with time is shown in Figure 13. It is clear from the Figure 13 that maximum torque 250 can be achieved using the proposed specifications. With the help of this modeling and simulation solar PV powered Country boat can be implemented practically.

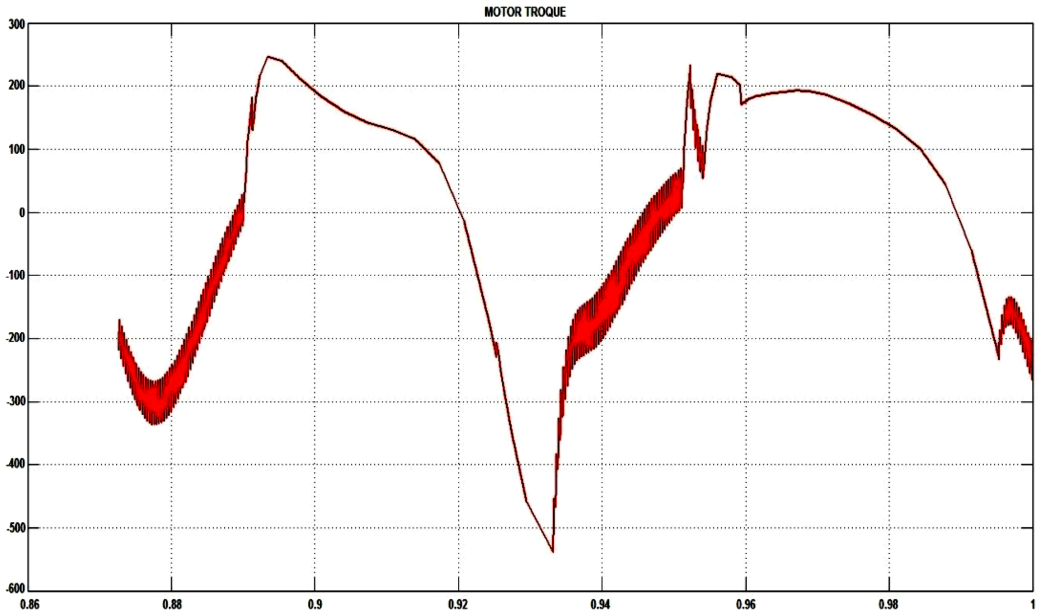

Figure 12: Output torque of single phase induction motor

Conclusion

Solar PV powered country boat using buck-boost chopper, PWM inverter and single phase induction motor is proposed here. It has been found that any improvement in diesel engines to decrease the NO_x will increase the PM in exhaust gas. If any attempt is made to reduce the amount of NO_x in exhaust gas of diesel engine fitted country boat by reducing the combustion temperature, PM will increase proportionately. But green powered sailing country boat eliminates the problem of NO_x and PM emission both. The effectiveness of the proposed control scheme is tested. This is a new and innovative application which is fully environmental friendly and is almost polution less. As the upper portion of the boat is unused, solar panels are implemented in that portion quite easily, no extra space is required. Fuel cost is not required in day time due to the presence of sunlight. Use of induction motor overcomes the NaCl deposition problem in commutator segment. Also, the energy payback period will be lesser than a diesel run boat. Furthermore, the PV panel provides the essential protection to the passengers from the straight sunshine and also from the rainwater. Use of fluorides in place of glass can reduce the weight of PV module which reduces the total boat-weight significantly. The reduction of tare-weight of country boat results in increase of passenger capacity at the time of sailing.

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Authors

SOUMYA DAS received his Bachelor degree in 2007 from WBUT; He received his Post-Graduate degree in 2010 from Jadavpur University, West Bengal, India. Currently, he is working as an Assistant Professor in Electrical Engineering Department of University Institute of Technology, Burdwan University, India. He has total experience of 5 years in teaching. He is presently pursuing Ph.D. programme at the Department of Electrical Engineering, Indian School of Mines, Dhanbad-826004, and India. He has guided a large no. of B.Tech and M. Tech students. His current areas of interest are solar photovoltaic system, power electronics applications, computer aided power system analysis, High Voltage Engineering.

PRADIP KUMAR SADHU received his Bachelor, Post-Graduate and Ph.D. (Engineering) degrees in 1997, 1999 and 2002 respectively in Electrical Engg. From Jadavpur University, West Bengal, India. Currently, he is working as a Professor in Electrical Engineering Department of Indian School of Mines, Dhanbad, India. He has total experience of 18 years in teaching and industry. He has four Patents. He has several journal and conference publications in national and international level. He is principal investigator of few Govt. funded projects. He has guided a large no. of doctoral candidates and M. Tech students. His current areas of interest are power electronics applications, application of high frequency converter, energy efficient devices, energy efficient drives, computer aided power system analysis, condition monitoring, and lighting and communication systems for underground coal mines.

SUPRAVA CHAKRABORTY received her Bachelor degree in 2011 from WBUT; She received his Post-Graduate degree in 2013 from Tezpur Central University. Currently, she is Pursuing Ph.D programme in Electrical Engineering from Indian School of Mines, Dhanbad from July 2013.

AKANKSHA RANJAN received her degree of 'Bachelor of Technology in Electrical Engineering' in 2012 from Biju Patnaik University of Technology, Odisha, India. She has an excellent academic career and is presently pursuing her degree of 'Master of Technology in Power System Engineering' from Indian School Of Mines, Dhanbad- 826004, and Jharkhand, India.

MONIKA YADAV received her Bachelor degree in 2011 from Kurukshetra University; She is pursuing her Post-Graduation in Power System Engineering from Indian School Of Mines, Dhanbad, -826004, Jharkhand, India. She has one year of teaching experience in Swami Devi Dayal College Of Technical Education, Panchakula , Haryana, India.