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Research Article

Design and Implementation of a Single Phase Sinusoidal Pulse Width Modulation Inverter Based Microcontroller for Wind Energy Conversion Systems

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Abstract: Aim of study describes design and implementation of inverter that working by sinusoidal pulse width modulation technique for small wind generation. SPWM technique is used as a switching pulse for turning on and off MOSFET's/IGBT's to generate an alternating current waveform at the output of an inverter circuit. This inverter based PIC18f4431 microcontroller that used to induce a true sine waveform for conformity with loads. The use of this microcontroller yields enhanced operations, fewer system components, lower system cost and increased efficiency. The designed inverter is examined in a practice on many AC loads and is necessarily concentrated upon low power electronic applications like a lamps and a fan etc. the enhanced model can improve the inverter output wave form and reduce a total harmonic distortion in remarkable way. A finished design is simulated in Proteus and Simulink software to ensure output results which is verified in the laboratory.

Keywords: AC, INVERTER, PIC Microcontroller, SIMULINK, SPWM, THD, WECS

INTRODUCTION

The utilization of the wind energy has a very long tradition. Some turbine studied the grid linkage issue of AC to DC to AC inverter interconnection the wind energy conversion systems WECS. Generality trendy turbine inverters are enforceda commutative pulse width modulation inverters to lets a constant voltage and a constant frequency output with a high-quality power. Both voltage source voltage controlled inverters and voltage source current controlled inverters are used in wind turbines (Maurya, 2014). Converting the Direct current DC to an alternating current AC this process are known as inverters. Inverters position are change a DC input voltage to an AC output voltage of required magnitude and frequency. Inverter output could be constant or adjustable voltage at a specific or adjustable frequency. The adjustable output voltage can be get it by modifying the input DC voltage and keeping the gain of the inverter fixed. Otherwise, if the DC input voltage is fixed and is not controllable, a variable output voltage can be get it by changing the gain of the inverter, which can be completed by a pulse width modulation PWM control inside the inverter. The gain of inverter may be known as the ratio of the AC output voltage to DC input voltage (Rashid, 2004). The SPWM is a powerful technique. It's mainly widely used in power electronics applications such as a motor driver, UPS and renewable energy systems (Ghalib *et al*., 2014). Usually the inverters witchemploy PWM switching techniques have a DC input voltage which is mostly fixed value. There are several ways to implement the pulse width modulation to shape the output to be AC power. A common method is a sinusoidal pulse width modulation SPWM will be described. To introduce output as a sinusoidal waveform at an exact frequency a sinusoidal control signal at the specific frequency is compared with a triangular waveform (Zope *et al*., 2012). The aim of this design is to take the place of the conventional method using PIC microcontroller which is able to store instructions that generate the required pulse width modulation waveform owing to the internal PWM module. This module has a variable frequency pulse width modulation signal which controlled of the consumed voltage on the gate drive by the PIC18F4431 microcontroller. Microcontroller technology evaluation has made it possible to perform functions that were earlier done by analog electronic components. With multifunctional approach, microcontrollers today are able to accomplish functions like comparator, Analog to Digital Conversion (ADC), setting Input/Output (I/O), counters/timer, among others replacing dedicated analog components for all given tasks, extremely reduction the number of components in circuit and thus, lowering the cost of components. The flash programming/ reprogramming of the microcontrollers make it very flexible. Uses of microcontrollers in control of WECS increases the efficiency of control process for grid

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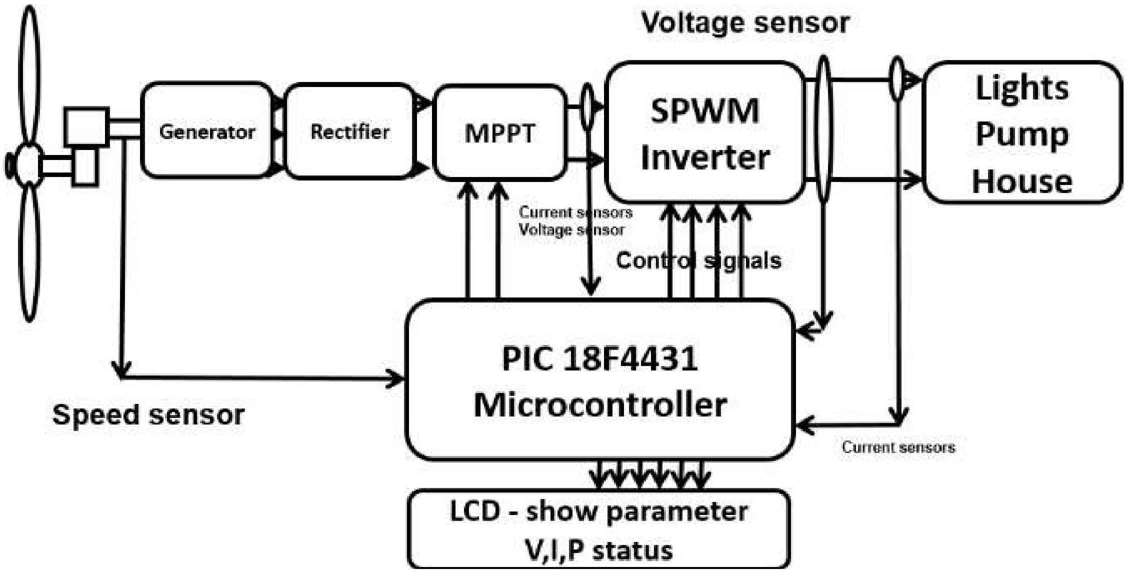


Fig. 1: Wind energy conversion system

connected to perform varied functions and tasks from the instrumentation for sensing current, sensing voltage and frequency of power transferred to the grid to optimizing the output power by sensing proper wind speed for turning OFF/ON the system. Due to varying nature of wind, the proposed design should be able to operate under different wind speed conditions, while keeping a fixed frequency and voltage. The designed inverter must be able to work with 500W small Wind Turbine, has output voltage 240V and frequency 50 Hz power supply for a house loads and also adequate to be transferred to grid. Also, must decreases the Total Harmonic Distortion (THD) (Zaidi *et al*., 2010). Figure 1 shows Wind energy conversion system.

PROBLEM STATEMENT

The inverter is the most important device to utilize the renewable energy sources efficiently. The sinusoidal pulse width modulation technique is one of the most popular PWM techniques for harmonic reduction of inverters (Raju *et al*., 2013). The electronic appliances that powered by the inverter will be influenced by the harmonic contents. Those harmonics in the inverter output rely on the pulses numbers per cycle. A lot of researches concluded the output waves are not similar.

In observing the losses problem and the pulses numbers per cycle have relations. The use of high switching approach will contribute to the high power losses. The next factors should be considered during the design:

- The materials cost
- The filter size
- The losses of MOSFET's/IGBT's
- The harmonics of the output waveform

METHADOLOGY

The system uses PIC 18F4431 microcontroller to generate Sinusoidal Pulse Width Modulation SPWM, the technique used to produce nearly true sine wave output from DC input. Pulse Width Modulation is the process of different the width of pulses to control the output voltage of inverter. In SPWM, the width of each pulse of a pulse train is varied in proportion to the amplitude of a sine wave evaluated at the center of the same pulse. The distortion factor and lower order harmonics are reduced significantly. The gating signals are generated by comparing a sinusoidal reference signal with a triangular carrier wave of frequency Fc. The frequency of reference signal Fr, determines the inverter output frequency and its peak amplitude, controls the modulation index (m) and Vrms output voltage (V_O). The number of pulses per half cycle depends on carrier frequency. The sine wave is considered as reference signal, while a triangular wave is treated as the carrier wave. The frequency of reference signal determines the inverter output

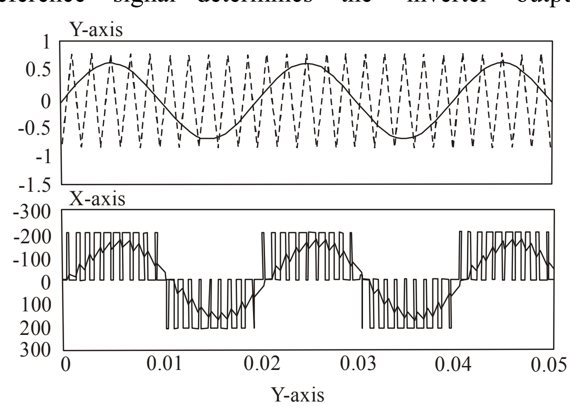


Fig. 2: SPWM generation

frequency and its peak amplitude controls the modulation index. The idea is to change the output state at the intersecting point of the two waves (Haider *et al*., 2012). Figure 2 shows SPWM generation in above mentioned method.

THE SYSTEM AND CHARACTERIZATION OF THE PROPOSED DESIGN

The basic circuit diagram of the PIC controlled single phase inverter draw using MATLAB/ SIMULINK is shown in Fig. 3. The system comprises of a control circuit and power switches in standard H-bridge circuit, switches G1, G2, G3 and G4are arranged in regulation to invert DC power to AC power at the required level and frequency (Ismail *et al*., 2006).

The control circuit section is comprises of PIC board, MOSFET driver. 8-bit PIC18F4431 microcontroller has 40-pin Low Power Microcontroller, 16 Kbytes Flash Program Memory, 256 bytes EEPROM Data Memory, 768 bytes SRAM Data Memory, 36 input output I/O Pins, One 8-bit and Three 16-BitTimers, 10-bit Nine Channels A/D Converter, 14-bit up to Four Channels Power Control PWM (Singh *et al*., 2014). The peripheral interface controllers (PICs) are the integrated circuits based on CMOS technology. The main components of a PIC are Input/Output (I/O) pins RAM, EPROM and EEPROM. These components are combined in the same integrated circuit to reduce the size, the cost of the system and make design of the system easier. The address bus, the data bus and the control bus connecting the components are placed in the PIC circuit by the manufacturer. Due to of these advantages, PICs have been preferred devices in practical control applications. The microcontroller has been programmed to generate SPWM for gate pulses by comparing a triangular carrier wave in this study 20000 Hz and a sinusoidal reference wave in 50 Hz and modulation index (m) variable from 0.5 to1.00. The output voltage of full H-bridge called fundamental voltage can be determined by the Eq. (1):

$$V = m \times Vdc \text{ (Vpeak)} \tag{1}$$

The sine wave of desired frequency is generated from the stored look up table. There is optical isolation between the controller and power circuit. The power circuit topology chosen is a full H-bridge Inverter because it is capable of delivering high current at low voltage. Figure 3 shows the full bridge inverter topology. It consists of DC voltage source, four switching elements MOSFETs, LC filter and load. The LC filter is desired to preparing the signal sinusoidal in physical. The improved of the quality of wave form by putting an LC filter at the output of the SPWM inverter circuit. For design an LC filter, there are several methods available. The efficient performance can be get it by using related studies in simulation and experimental. A rule of thumb in control theory is that the frequencies of such a configuration have to have at least a factor of 10 between them to decouple the effects. According to this rule, for 50 Hz fundamental frequency, resonance frequency has to be at least 500 Hz. Resonance frequencies is determined by the product of L and C. The resonant frequency of the combination can be determined from the Eq. (2):

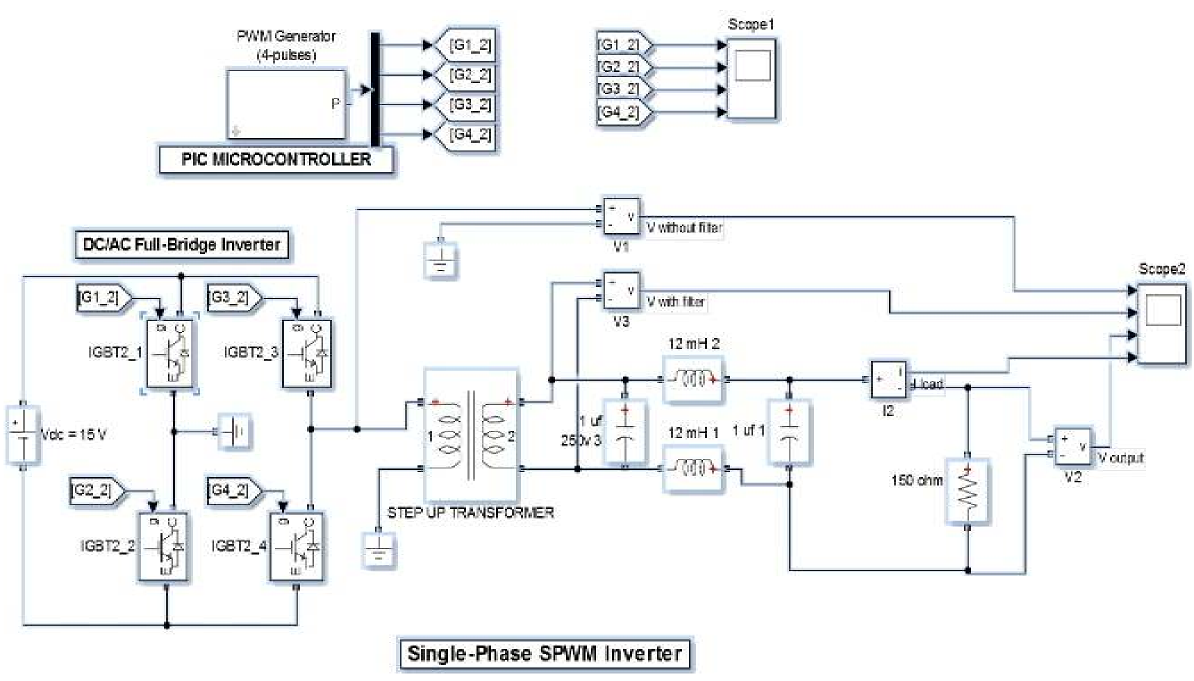


Fig. 3: Schematic diagram of the system

$$F = 1/2\pi\sqrt{;\ LC} \quad (2)$$

SOFT WEAR ALGORITHM

Figure 4 shows the flow chart of single phase sinusoidal PWM signal. In this flow chart "Initialize the program variables, Vref, lookup-table and PWM module" and initializes the ports in software by which the ports work as output ports. Then “Initialize Sine Look up Table” stores the sampling value of sine wave. Those sampling value will go in PWM duty cycle register of PWM module. Then the signal becomes Sinusoidal PWM signal.

The Pseudo code contains the following steps:

1- Initialize the program variables, Vref lookup-table and PWM module
2- Setting the address of the look up table.
3- Calculating the PWM modulation index.
4- Measuring the amplitude of the output voltage.
5- If there is equality between the output voltage and reference voltage, then returns to step 2.
6- If the output voltage is more than the reference voltage, then the address of the look up table is incremented and returns to step 3.
7- If the output voltage is less than the reference voltage, then the address in the look up table is decremented and returns to step 3.

Gate driver: The MOSFETs driver TLP250 has one channel, 5000 Vrms isolation voltage, 1.5 A maximum continuous output current 20 mA forward current, 1.6V forward voltage, 5V reverse voltage and operating supply voltage from 10V to 35V. TLP250 consists of a light emitting diode and an integrated photo detector. The output waveform will have the same waveform as the input waveform except the magnitude and power. TLP250 ICs are commonly used driver ICs for IGBTs or MOSFETs. The gate driver circuit is shown in Fig. 5.

The input forward voltage will typically be between 1.6 V and 1.8 V. The propagation delay time will typically be between 0.15 µs and 0.5 µs and the maximum operating frequency is to be 25 kHz in datasheet. When designing circuits with TLP250 a 100 nf bypass capacitor (ceramic capacitor) is in the output of the driver. This capacitor is called a boot strap capacitor, used to protect the driver from dv/dt.

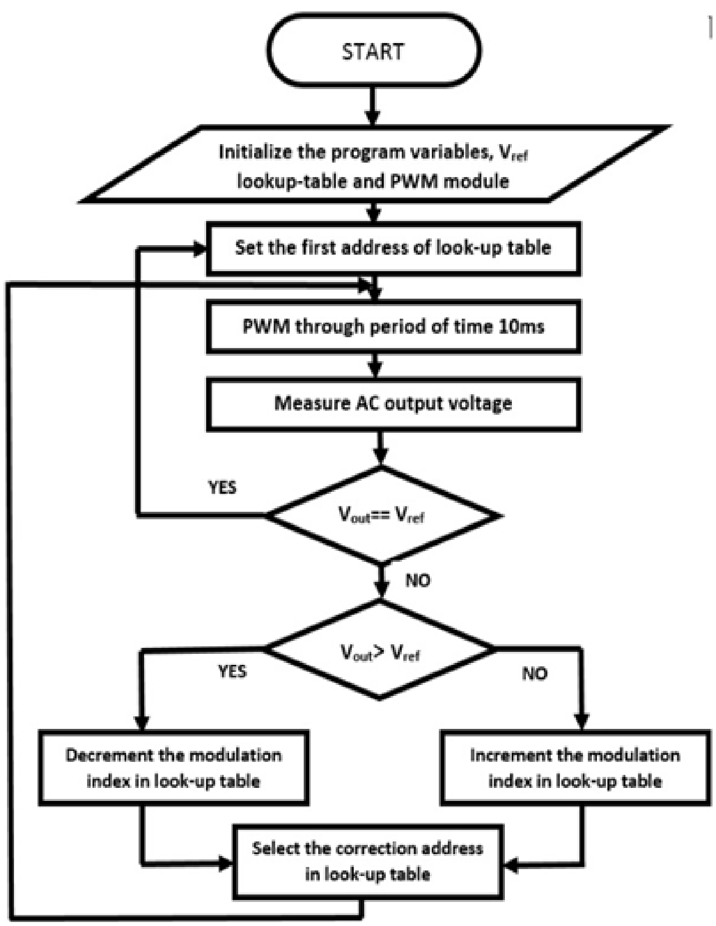


Fig. 4: The flow chart for programming the signal phase inverter SPWM

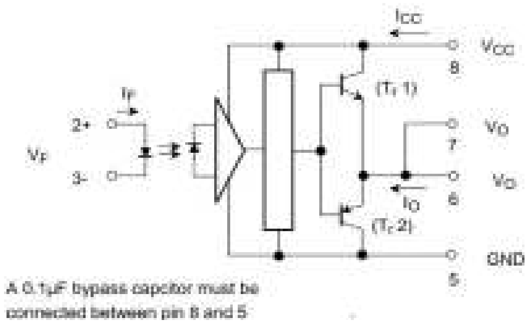


Fig. 5: TLP250 gat driver

RESULTS AND DISCUSSION

The H-bridge circuit diagram of the inverter with the drive circuit is shown in Fig. 6. In this portion the design of the hardware configuration. The H-bridge inverter is composed of four IRf3205 MOSFET switches rated 55V, 110A and four anti-parallel diodes in simulation circuit. This switch has ultra-low resistance 8 mΩ, leading to power dissipation and greater efficiency. The difficult thing is directly connect interface an MOSFET to PIC18f4431 microcontroller. For proper operation of MOSFETs, voltage and current levels of PIC microcontroller output signals failure to operate the MOSFETs (Q1, Q2, Q3 and Q4). TLP250 MOSFET driver circuit used to amplify PIC output signals to the required level for operating the MOSFETs and isolates the PIC microcontroller from the power circuit. The isolation circuit is used to isolate signals for protection and safety between control circuit and power circuit. This is done by using high speed TLP250.

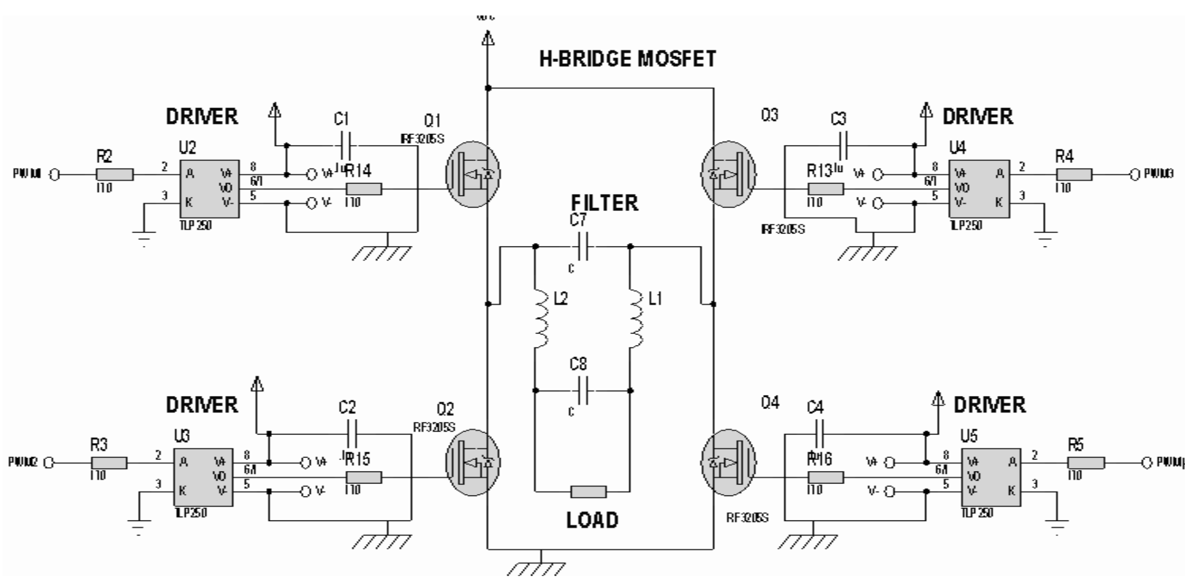


Fig. 6: Proteus schematic of full H-Bridge with Tlp250

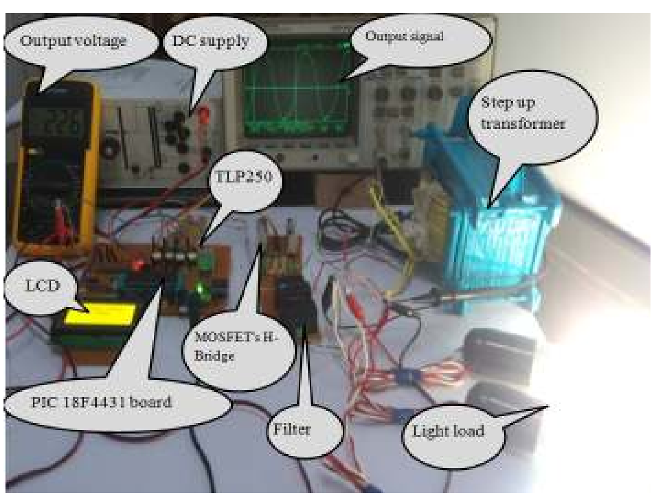


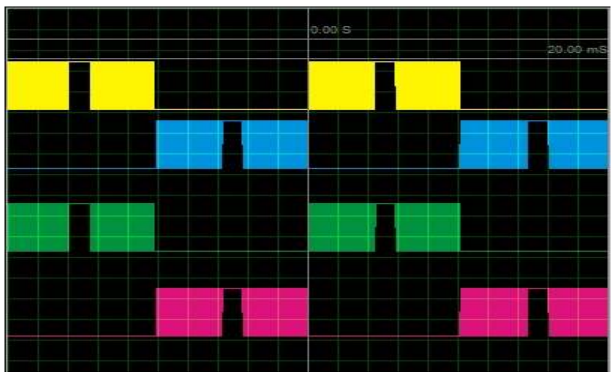
Fig. 7: Hardware setup of the sine wave inverter with load

The practical setup is composed of PIC 18F4431 board, DMM, Tlp250 MOSFET driver circuit; full bridge inverter circuit (four mosfet's irf3205), DC power supply, LC filter and oscilloscope are used to measure the experimental results as shown in Fig. 7. The proposed system is designed to provide a 50-Hz sinusoidal waveform on the load. The PWM is switching frequency of 20 kHz. As 400 PWM samples complete a sine wave 360o, the frequency of the resulting sine wave will be, F = 20 kHz/400 = 20000 Hz/400 = 50 Hz. The lookup table values can be calculations from Eq. (3):

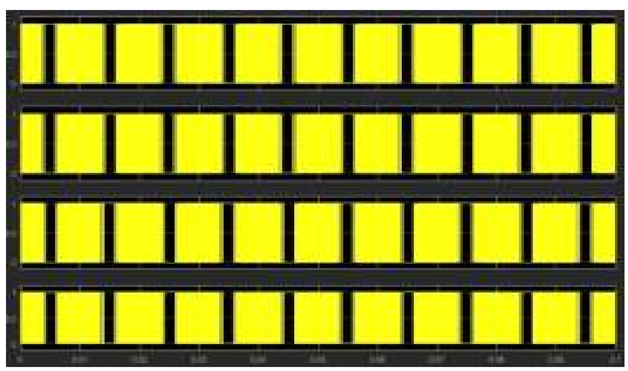
$$Yi = PWM_{max} \text{ X } \sin (I \text{ X } 180/200) \quad (3)$$

where, PWM =0-1023, (PWM_{max} = 1024) i = 0, 1, 2…,200

The simulations and the experimental results of output control circuit have been done using SIMULINK and Proteus software to investigate the validity of the switching technique strategy. The gate pulses generated for the inverter are shown in Fig. 8. In this figure two pulses of unipolar sinusoidal pulse width modulation and two square pulses are generated by the control circuit. The pulses signals are then fed to the MOSFETs connected in full bridge configuration. The four switches MOSFET Q1, Q4 and MOSFET Q2, Q3 are operated by unipolar sinusoidal pulse width modulated has frequency 50 Hz which is 180 degree phase shifted



(a)



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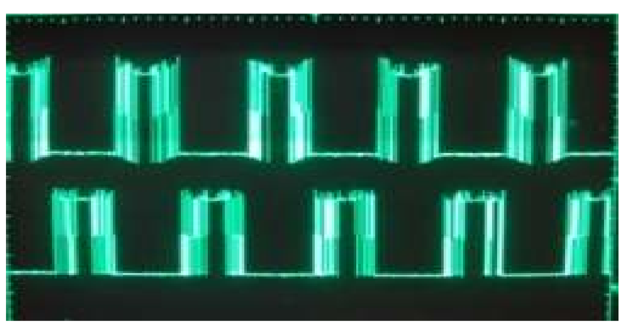
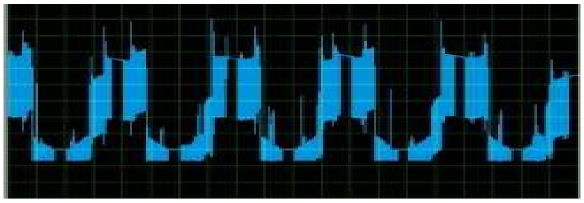
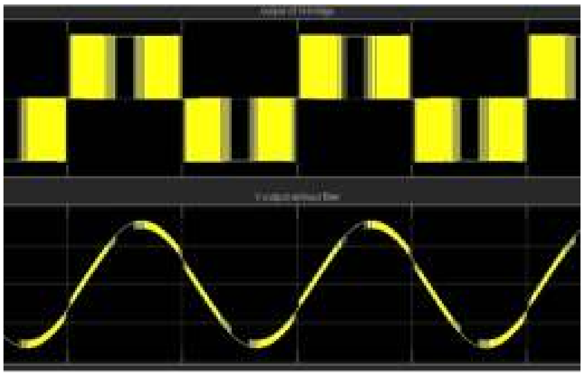


(c)

Fig. 8: (a) Gate pulses simulation in proteus, (b) Gate pulses simulation in SIMULINK and (c) Gate pulses in experimental



Output before filter in proteus



Output before filter in Simulink

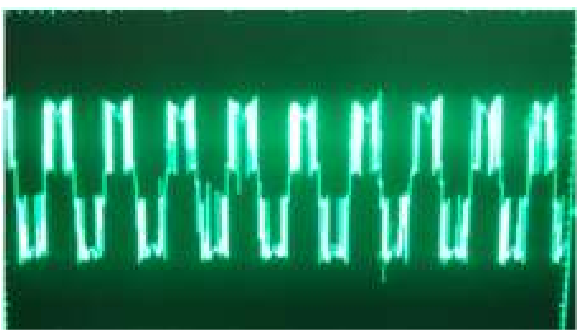
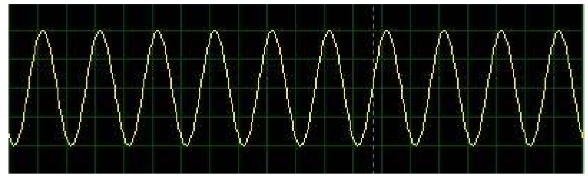


Fig. 9: Output before filter in experimental

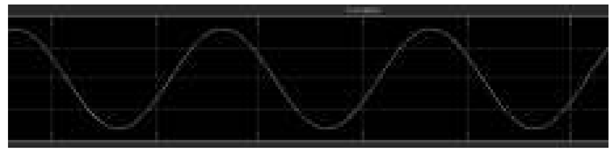
Table 1: Design parameters

Elements	Parameters
MOSFETs IR3205	Rated 55V, 110A has ultra-low resistance 8 mΩ
Inverter filter	Capacitance: 1μF, 250 V Inductance: 12 mH Resonant Frequencies: 500 Hz
TLP250	High level input voltage: 3.3 V High level input current: 5 mA maximum operating frequency: 25 kHz
Output voltage	220-250 Volts (AC)
System frequency	50-Hz

by to each other, signals SPWM1 and SPWM2 which has 20000 HZ and the difference is only SPWM1 signal leading SPWM2 by 180° phase shifted by to each other or half cycle every half cycle takes 10 ms. In the Fig. 8a shows the gate pulses unipolar sinusoidal pulse width modulation simulation in proteus, Fig. 8b shows the gate pulses unipolar sinusoidal pulse width modulation simulation in Simulink and Fig 8a shows the gate pulses unipolar sinusoidal pulse width modulation simulation in experimental, which is given to switches Q1, Q4 and switches Q1, Q4 continuously.



Output after filter in proteus



Output after filter in SIMULINK

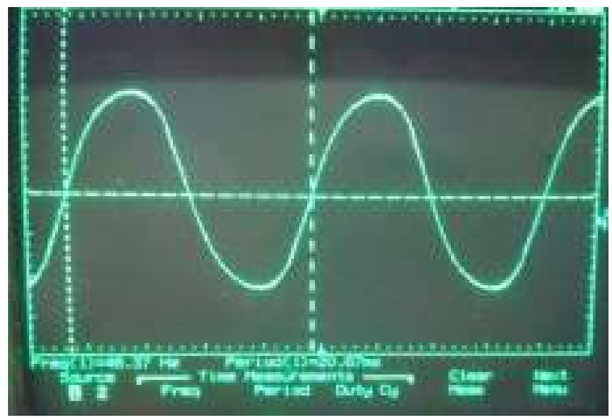


Fig. 10: Output after filter in experimental

Figure 9 shows the experimental and simulation results of output waveform before filter of the inverter. The output voltage is a periodic waveform which isn't sinusoidal wave but to access a required output AC sinusoidal wave signal by added the LC filter in output of the circuit.

The reference wave amplitude adjusts the amplitude of the generated AC voltage and the Reference wave frequency determines the frequency of the generated AC voltage. The frequency of the output waveform of the simulation and the experimental results is 50 Hz. This frequency is exactly equal to grid frequency. The output sine waveform of the full H-bridge single phase inverter and the simulation results of output waveforms after filter of the inverter to ensure the output waveform results a nearly pure sine wave is practically verified. Figure 10 shows the results of SIMULINK, simulation and Proteus software.

The generation of output voltage wave form of ideal inerters should be sinusoidal. The measured Total Harmonic Distortion (THD) are very small THD = 0.19% for output waveform as shown in Fig. 11. The output voltage waveforms show that the experimental results are very similar to simulation results. As expected, the higher the switching frequency, the smoother the output voltage waveform. The design parameters of the test device are shown in Table 1.

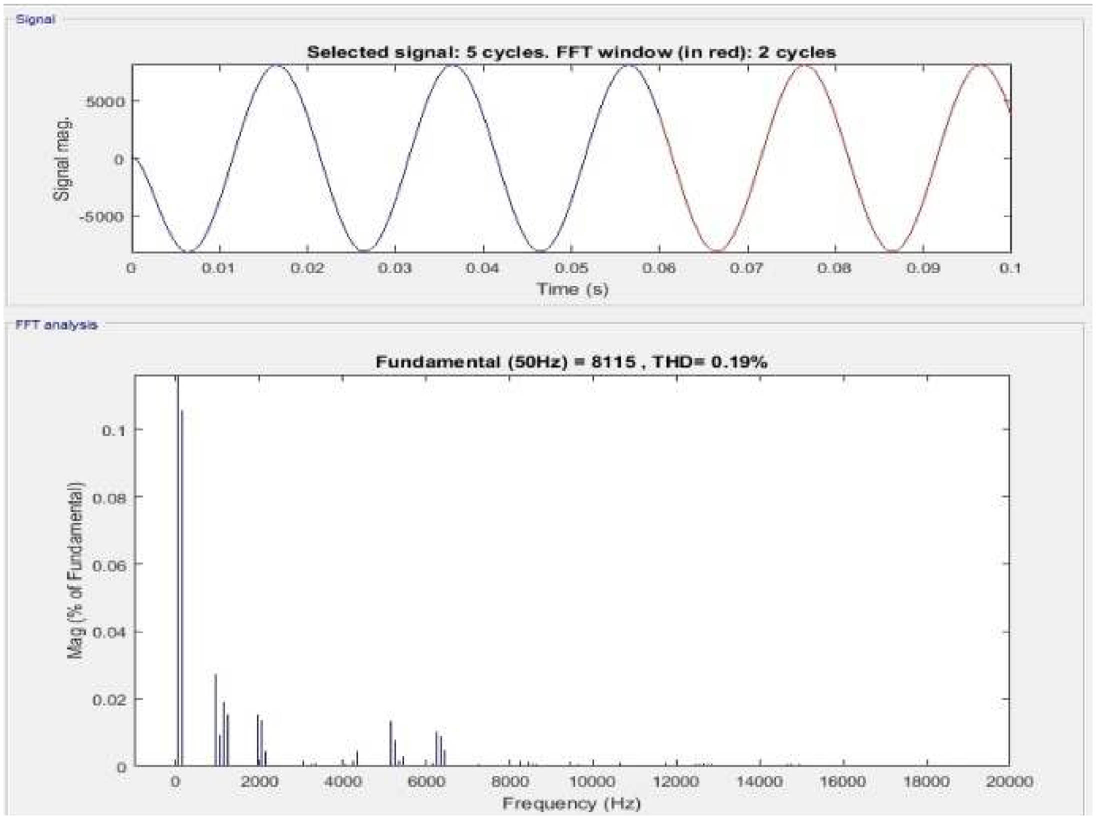


Fig. 11: Total harmonic distortion of output wave form in Simulink

CONCLUSION

This study describes the design and implementation of a digitally controlled single phase SPWM inverter to develop the control circuit for a small wind generation system, which has been implemented using PIC18f4431 microcontroller based control applications. These inverter topologies can be used for WECS applications and particular inverters for the AC-Module. The unipolar SPWM pulses are generated for fundamental frequency of 50 Hz and its switching frequency of 20 kHz are simulated in Proteus and SIMULINK simulator. The output voltage of inverter is changing by modulation index of the unipolar Sinusoidal Pulse Width Modulation pulses according to the loads conditions which is given as the gate pulses to inverter switches. The experimental results 240V, 50Hz and THD = 0.019% for output wave form has been performed for output voltage of inverter for different values of loads. The simulation results which are performed at SIMULINK and Proteus software are compared to the experimental results to perform by the LAB-module.

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