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Development of a single –phase h-bridge inverter based on microcontroller sinusoidal pulse-width modulation scheme for residential load applications

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Abstract
This paper presents the development of a single-phase H-Bridge inverter based on microcontroller sinusoidal pulse width modulation scheme for residential load applications. The quests to reduce the harmonic contents of the conventional inverter necessitated this research paper. The power switches firing signals are generated using a microcontroller (AT-MEGA 328). Furthermore, the microcontroller is able to store the required commands to generate the necessary waveforms to control the amplitude and frequency of the H-bridge inverter through appropriate design. A pure sine wave of output voltage and current are obtained with reduced total harmonic distortion. This inverter is designed to be for stand-alone from a direct current supply (battery). In this paper, a block diagram is developed, which contains the battery, H-bridge inverter, step-up transformer, L-C filter and the control system. All these blocks are discussed. Finally, MATLAB/Simulink simulations and experimental results are generated and discussed. The 1.2 kVA designed prototype was tested with a 48.5 ohm resistive load and found equal value of voltage THD to be less than 4.00 % with 220 Vrms.

Keywords: H-bridge inverter, Microcontroller, Single-phase, Sinusoidal Pulse Width Modulation (SPWM).

1. Introduction

The conversion of regulated or unregulated Direct Current (DC) to constant or adjustable Alternating Current (AC) using a suitable power electronic circuit configuration is termed Power inverter. This conversion can affect the output voltage / current magnitudes or frequency. Thus, one of the main objectives of the inverter is to use a DC voltage source to supply a load requiring AC, it is useful to describe the quality of AC output, (Rahman, et al., 2012). The input of the inverter is taken from various DC sources like a battery, photovoltaic, fuel cell, alternator, wind turbine, etc (Shaaban et. al., 2017) and also in standalone system (Rodney et. al., 2020), distributed and renewable energy system (Islam et. al., 2019), avionic system (Lavenya et. al., 2022), aircraft system (Parripati et. al., 2020). Controlled power inverters such as voltage and current sources have gained wide application in extraction of energy generated by the wind turbines (Maurya, 2014). There are two common types of circuit configurations used in single-phase inverter which are include half-bridge and full-bridge configurations. The half-bridge topology is associated with high harmonic contents. Inverters have been widely used for applications, from small switched power supplies for a computer to large electric utility applications to transport bulk power (Azuan, 2017).

The need of the power rating inverter is required to operate electrical and electronic appliances smoothly. Most of the available commercially uninterruptible power supplies (UPSs) are square wave inverters or quasi sine wave inverters. Electronic devices, managed by these inverters will be damaged due to the contents of the harmonics (Mamun et al., 2013; Kashenas et al., 2005; Senthilkumar et al., 2010). Available pure sine wave inverters are too expensive and the output is non-sinusoidal, but the sine wave generation is extremely important in power electronics. (Islam et. al., 2015; Kjaer et. al., 2005) reported on transformer less, lower THD and highly efficient inverter system, where pure sine wave output voltage was achieved but it could not solve isolation problem. For getting a pure sine wave, the sinusoidal pulse width modulation (SPWM) switching technique is applied. This method involves a certain pattern of switching used in the DC-to AC inverter bridges. (Hassaine et al., 2015; Kerekes et. al., 2011). Among other control schemes, the SPWM is most outstanding technique. In power electronics application systems such as the motor driver, Uninterrupted power supply (UPS), and the renewable energy systems, etc, SPWM is most widely applied, (Ismail et al., 2006).

SPWM is generated by comparing the reference sinusoidal signal of the desired frequency and carrier triangular signal of very high frequency through a comparator (Zope et al., 2012). The comparator gives one state as output when the carrier signal exceeds the reference and gives a second state when the reference voltage exceeds the carrier voltage. To obtain the inverter controlled output voltage and reduced harmonic contents, the width of these pulses have to be modulated. The harmonics is mainly caused due to low switching losses and low electromagnetic compatibility (EMC's) (Dhambi et al., 2015). To replace this conventional SPWM control scheme, which has a high cost, size, weight and low reliability implications, ATMEGA 328P microcontroller method is proposed. A microcontroller system is used to control the inverter switching process (Meghriche, et al., 2006). The microcontroller provides the variable frequency pulse width modulation signal that controls the applied voltage on the gate drive by using the system of Arduino Uno (ATMEGA 328P). To change the real-time control algorithms without necessarily further changes in hardware makes the proposed system more rugged and flexible (Abhisek et al., 2011). Microcontroller technology evaluation has made it possible to perform functions that were earlier done by analogue electronic components. With a multifunctional approach, microcontrollers today can accomplish functions like comparator, analogue to digital conversion (ADC), setting input/output (I/O), counters/timer, among others replacing dedicated analogue components for all given tasks, extremely reducing the number of components in the circuit and thus, lowering the cost, size, weight of components (Ghalib et al., 2011) and above all a reduction in THD content. The advantage of the unipolar SPWM technique is that it only needs a small filter to produce sine waves and reduce Total Harmonic Distortion (THD), (Sundas, et al, 2018).

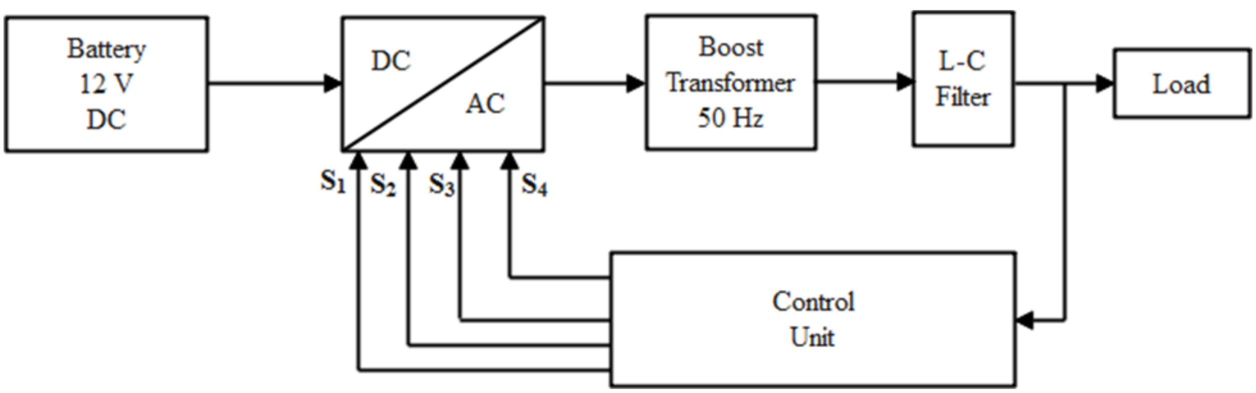

Fig.1: Block diagram of the proposed system

The block diagram of the whole system is depicted in Fig. 1. The system consists of a battery which serves as dc supply voltage, full bridge inverter circuit, boost transformer, filter circuit, microcontroller circuit for generating SPWM signals and duty cycle controller, opto-isolator or isolation circuit, gate drivers. The supply voltage is connected to full bridge inverter which converter the low supply voltage to a low modulated ac output voltage. Furthermore, the ac output voltage is fed to a step-up low frequency transformer which boosts the low primary voltage to a high secondary voltage. The output secondary voltage is then fed to L-C filter in-order to get a pure sinusoidal waveform which is connected to a resistive load. This paper is divided into four (4) sections, it is shown that section (1) presents the introductory part of the work, material and methods are detailed in section two (2), the simulation and experimental results are depicted in section three (3), and finally, in section four (4) a research conclusions are drawn. Thus, the purpose of this work is to analyze both simulated and experimental results of THD content for the unipolar SPWM switching techniques using digitized application. Also, the hardware prototype of the inverter using unipolar SPWM was developed to validate the simulation results.

2.0 Material and methods

In other to actualize the desired result from this research work, some hardware and software components were used. The range of the SPWM inverter circuit is to obtain the desired output voltage of 220 V ac, current of 3 A, a frequency of 50 Hz and a power rating of 1 kVA. The Hardware components of the designed circuit are: the DC voltage source (Battery), the H- bridge inverter configuration, L-C filter unit, boost transformer (50 Hz), the microcontroller circuit unit. The software components used in the design of this work are: Matlab/Simulink/ Simpowersystems and Proteus ISIS professional.

2.1 Battery

One of the major and common sources of dc voltage is from battery. The batteries are packaged in different voltage and current ratings. In this work, 12 V, 100 Ah, Ni-MH battery is used for discharging process. The battery is connected parallel to the h-bridge inverter, where the wire terminal "a" of the inverter is fixed to the positive terminal of the battery. Also, terminal "b" is connected to the negative terminal of the battery. The battery voltage is represented as V_{bat} as depicted in Fig. 2.

2.2 H-bridge Inverter

The H-bridge inverter topology is depicted in Fig. 2. The full bridge inverter configuration consists of four metal-oxide semiconductor field effect transistor (MOSFET) connected to form two poles. Each MOSFET contains anti-parallel diode for returning current path. The battery voltage (V_{bat}) is supplied to point 'ab', and a low amplitude voltage is generated at point 'cd'.

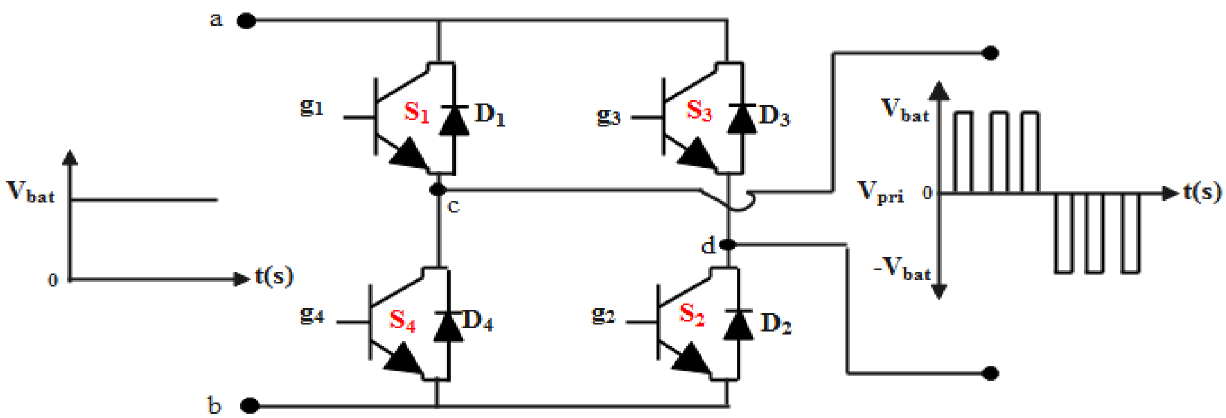

Fig.2: Full bridge inverter topology.

The gating signals are connected to g1, g2, g3 and g4 for activation of the power circuit. This connection involves driver and isolation circuits. The output voltage (V_{pri}) is fed to the boost transformer.

2.3 Transformer

The transformer used in this work is a single-phase, step-up shell-type transformer (SSSUSTT). This electrical equipment helps to transform electric power from one circuit into another circuit at the same frequency. It has the ability to raise or lower the voltage in circuit with a corresponding decrease or increase in current. The physical basis of a transformer is mutual induction between two circuits linked by a common magnetic flux.

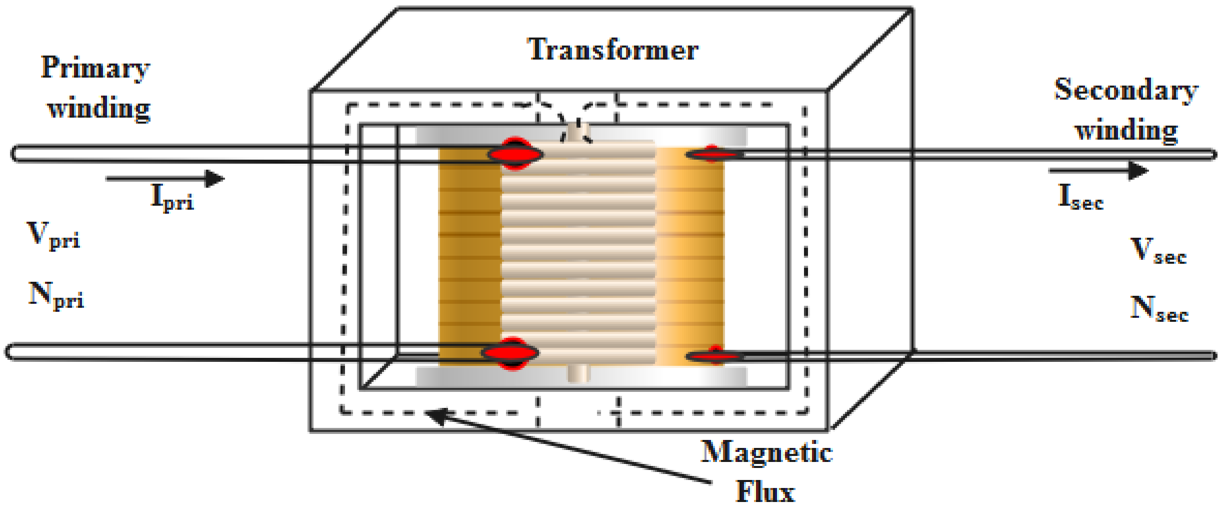

Fig. 3: Boost-Shell-Type Transformer Configuration.

In its simplest for, it consists of two inductive coils which are electrically separated but magnetically linked through a path of low reluctance as depicted in Fig. 3.

2.4 L-C filter

To reduce the total harmonic content and make the output signal become sinusoidal, an LC filter is required. The output voltage from the transformer (V_{sec}) is fed to the LC filter as depicted in Fig.4. The load voltage (V_o) is the output voltage from the LC filter.

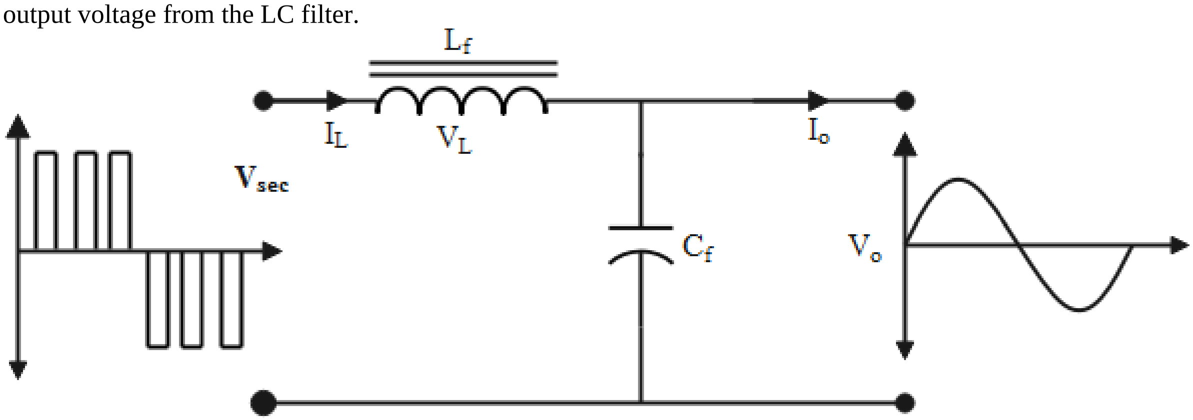

Fig. 4: The LC filter circuit configuration.

2.5 Control scheme

The switching signal for the inverter power circuit can be generated in an analogue way by using two high frequency carrier triangular waveforms and one sinusoidal reference waveform. By comparing the carrier with reference waveforms, the power switches firing signal are generated as depicted in Fig. 5.

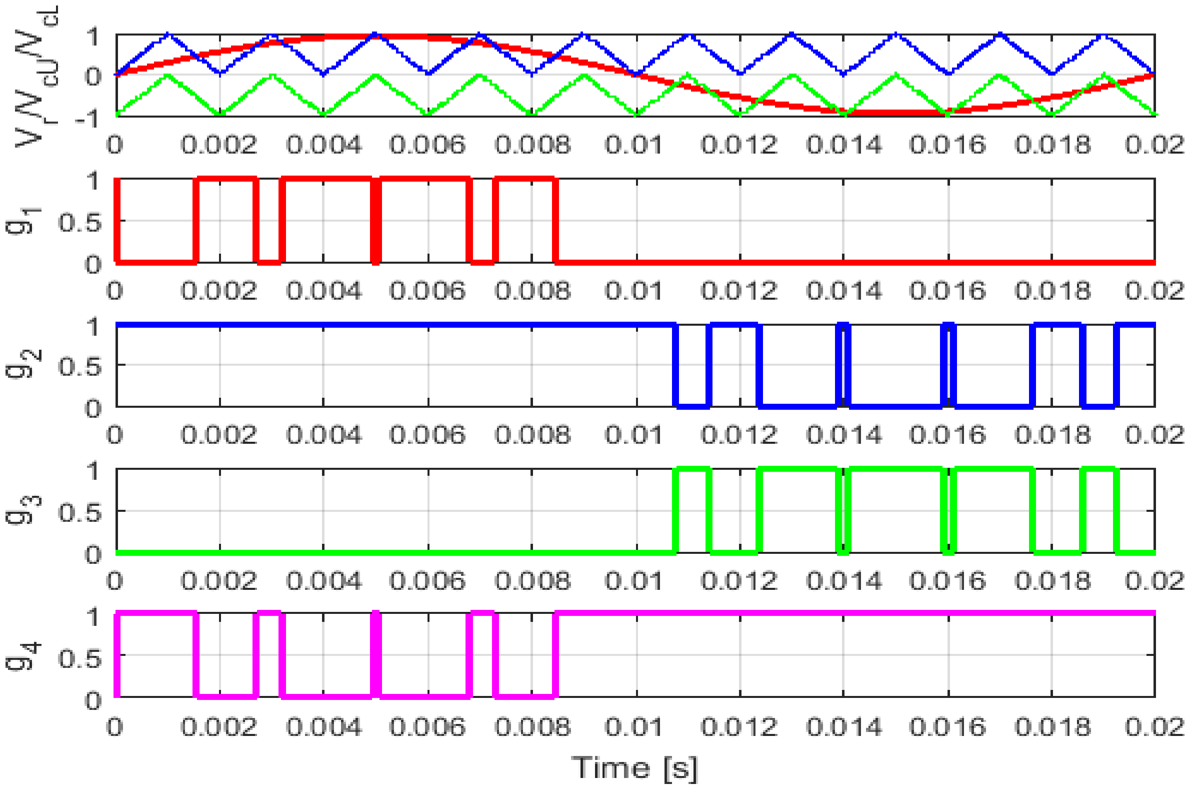

Fig.5: Waveforms of carrier and reference, and the switching signals for H-bridge inverter.

To reduce cost, weight and number of components, the SPWM signal was generated using ATmega328P, which the pin-out configuration is as shown in Fig. 6. The ATmega328P is a low-power CMOS 8-bit microcontroller based on the advanced virtual (AVR) enhanced reduced instruction set computer (RISC) architecture. By executing powerful instructions in a single clock cycle, the ATmega328P achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

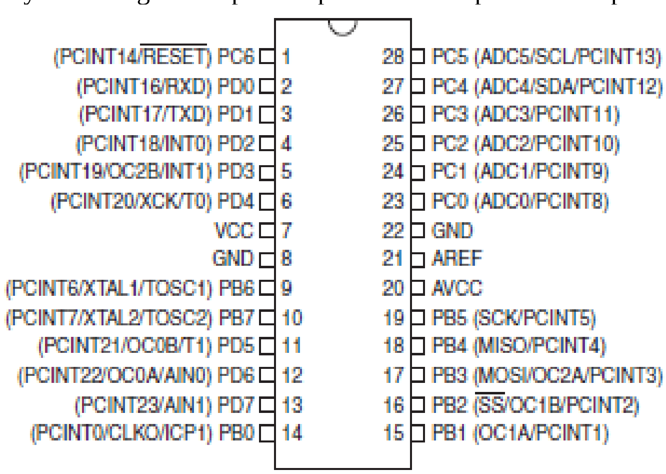

Fig.6: Pin-out Configuration of ATMEGA328P

To enable the design to be simpler, more reliable, low-cost, protective and less component counts, a microcontroller scheme is developed as the control circuit. The microcontroller has been programmed to generate SPWM for gating signals. In analogue form, a triangular carrier wave of frequency 3.5 kHz and a sinusoidal reference wave of 50 Hz are both compared to generate the required pulses. Modulation index (m) of the digital control varies from 0.5 to1.00.

3.0 Results and Discussions

Here, the simulation and experimental results are presented. The simulations have been performed using MATLAB/SIMULINK software to investigate the validity of the modulation technique. A 1 kVA single-phase power rating inverter was developed to validate the simulation results.

3.1 Simulation results

The simulation results of the inverter system are analyzed in Figs. 7 – 13. The battery voltage and power ratings are depicted in Fig.7. It is observed that the battery output voltage is 12 V and power rating is 100 A/H. This size of battery can last long depending on the load application. The battery capacity can be increased for more time duration of operation by parallel combination of the same size of batteries. Fig. 8 shows the voltage drop and current across the filter inductor. The inductor voltage fluctuates between the maximum and minimum output load voltage, therefore, the current takes a form of a sinusoidal waveform with little ripples.

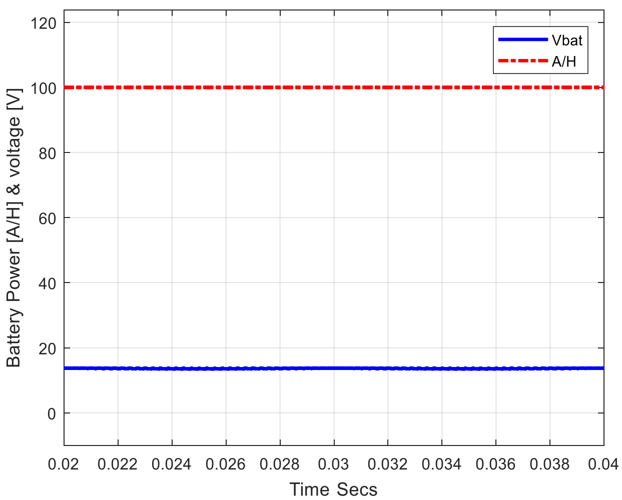

Fig.7: Battery amperage and input dc voltage

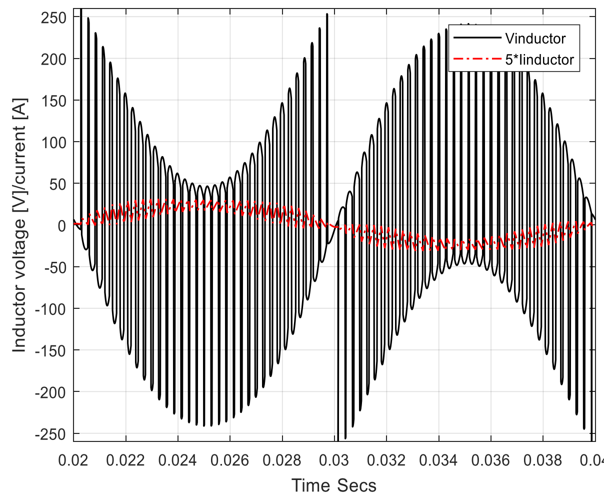

Fig.8: Voltage drop and current across filter inductor.

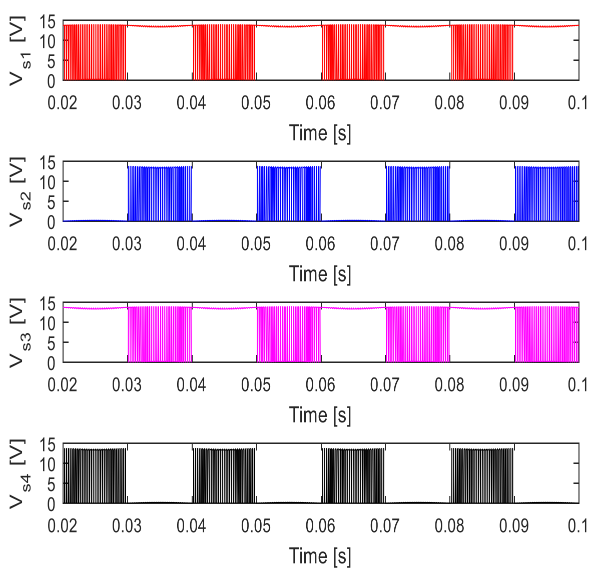

Fig.9: Firing waveforms of the H-bridge switches.

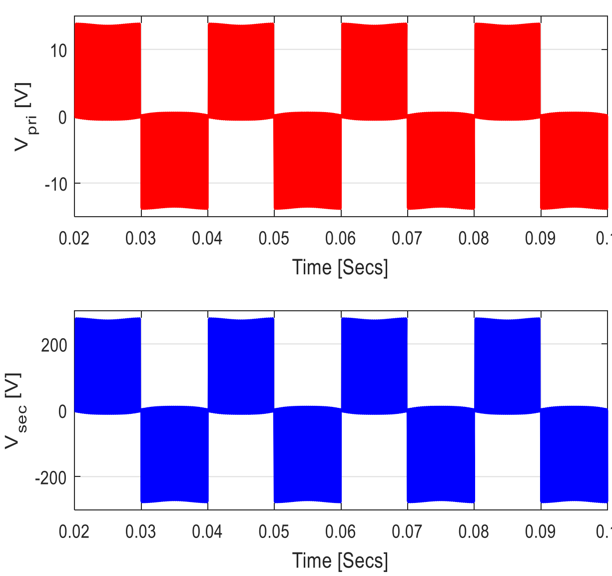

Fig.10: Transformer input-output voltages.

Figs. 9 and 10 show the switching signals and the transformers input - output voltages respectively. From Fig. 9 the four switching signal for the power semiconductors are shown. The V_{s1} alternates with V_{s4} and V_{s2} alternates with

V_{s3}. This modulation pattern has to be maintained to avoid bridge of the supply voltage. The pole voltage V_{s1} differs from the pole voltage V_{s2} by 180 ^{o}.

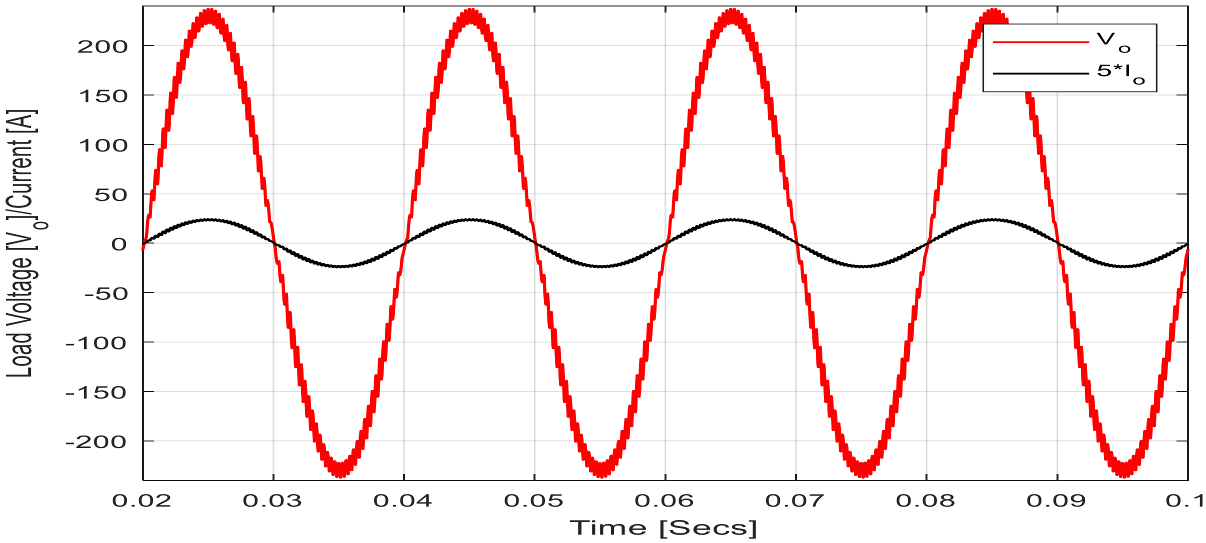

Fig.11: Waveform of inverter output voltage and current.

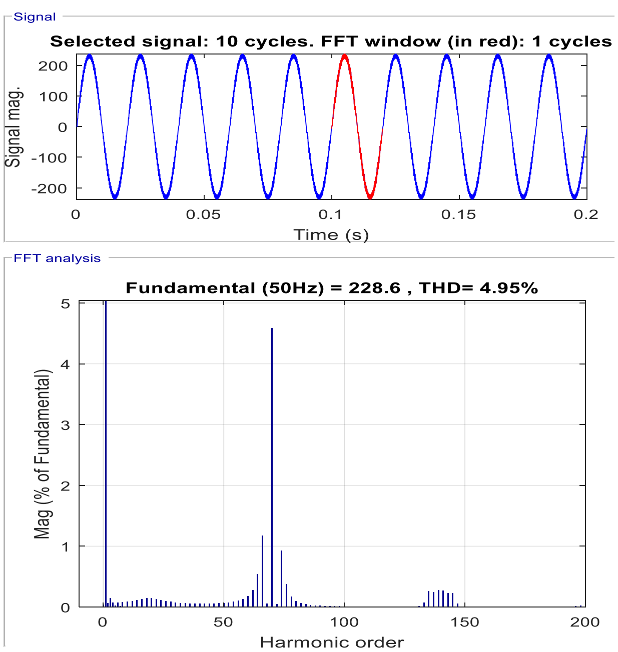

Fig.12: Waveform of output voltage THD

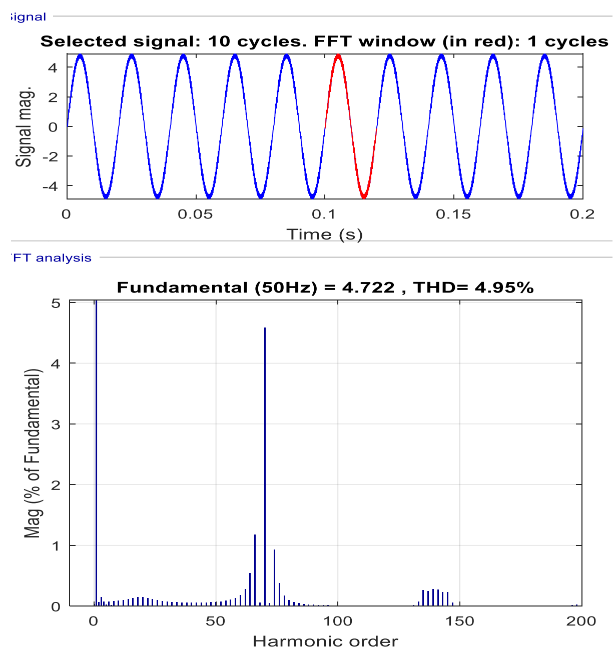

Fig. 13: Waveform of output current THD

The simulation filtered output voltage and current is display in Fig. 11.Their performance based on THDs were evaluated in Figs. 12 and 13. The output voltage THD in Fig. 12 showed a value of 4.95 % and 228.6 V r.m.s voltage value. While in Fig. 13 the output current THD displayed a value of 4.95 % with r.ms. value of 4.722 A.

3.2 Experimental results

The experimental results are shown in Figs. 14 – 20 as obtained in the Power Electronics Laboratory. The experimental prototype of the inverter system is displayed in Fig. 14. It consists of a Hantek DSO5102P; two channel digital storage

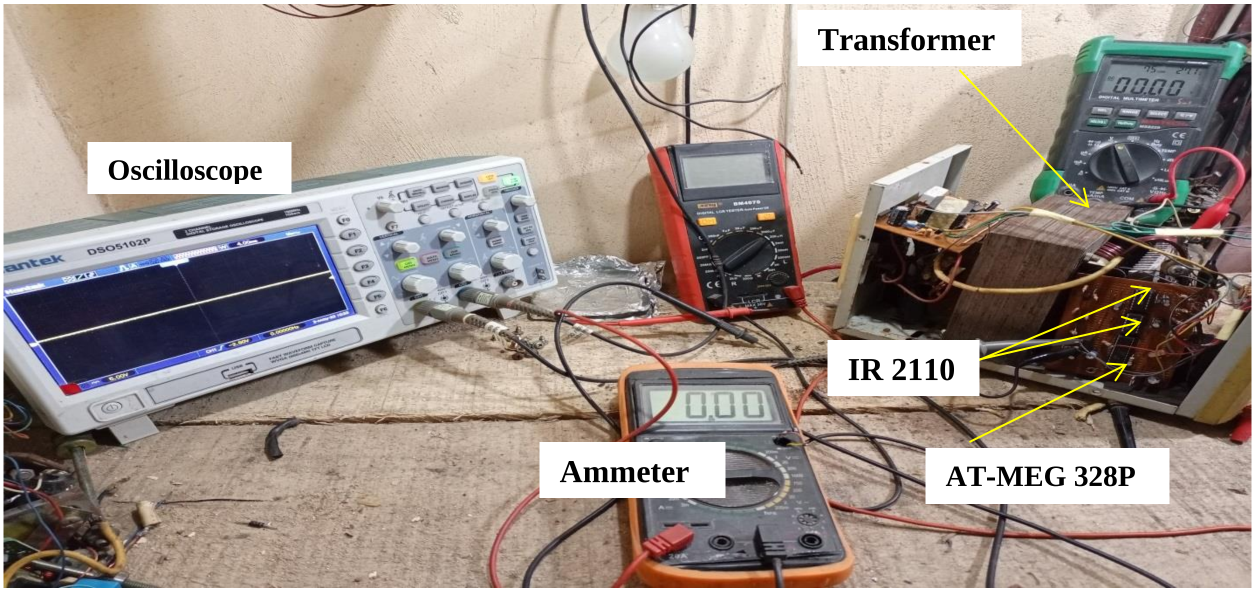

Fig.14: Experimental Prototype of the Inverter system

oscilloscope which was used to measure the experimental results. The battery voltage rating is displayed in Fig. 15, which indicates the value of the inverter dc input voltage. The experimental result for the gating signals for the power switches are depicted in Figs. 16, 17 and 18. Fig. 16 shows the modulated firing signal with the voltage drop across the power switch, S_1, and Fig. 17 displays two firing signals for power switches S_2 and S_4, the two switches alternates their operations, also their blocking voltage values displayed. Finally, Fig. 18 shows blocking voltage value of the power switch S_3. Fig. 19 shows the waveform of the output voltage of the H- bridge inverter which feds the primary winding of the transformer. It operates at low fundamental and high carrier frequencies. A boost output voltage was observed at the secondary side of the transformer which passes the LC filter to generate a pure sine wave as shown in Fig. 20. This figure shows the output voltage waveform from single phase inverter with resistive load. The waveform is pure sinusoidal with amplitude around 220 Vrms, 50 Hz and THD is around 3.7 %.

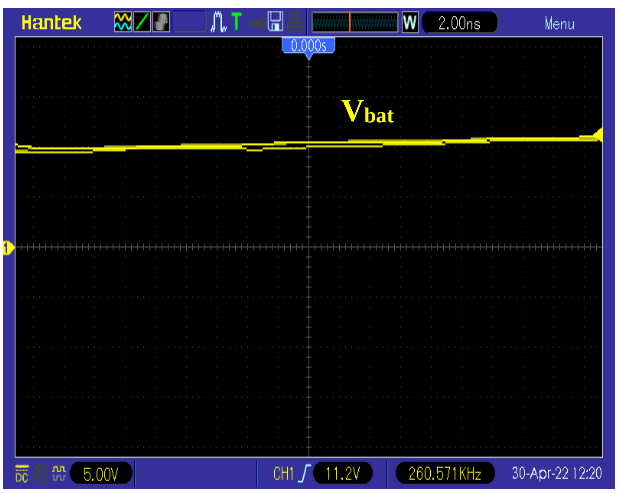

Fig. 15: Battery input voltage

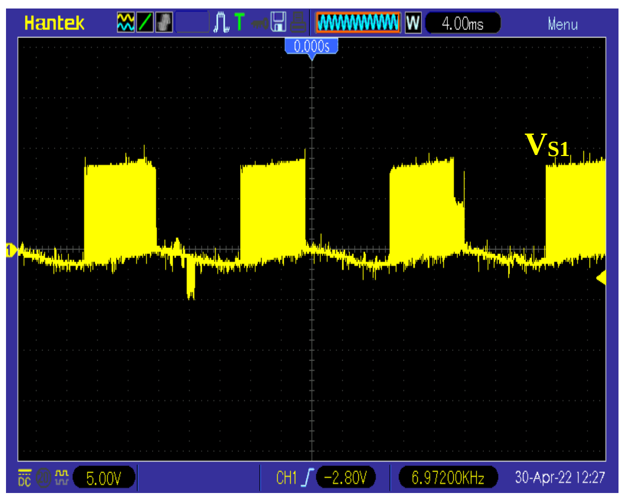

Fig. 16: Power switch voltage of S_1

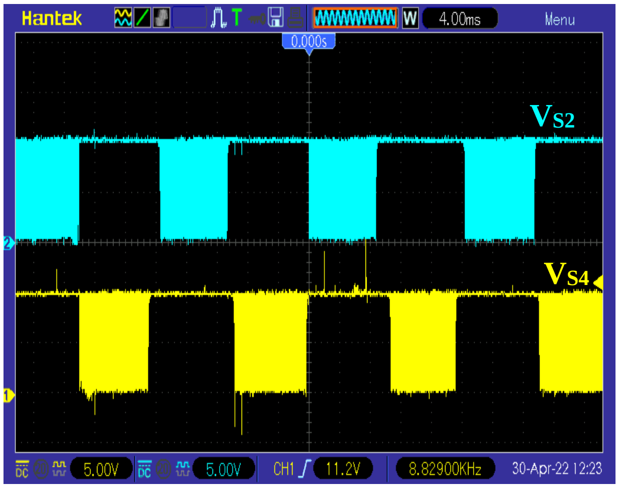

Fig.17: Power switches voltages across S_2 and S_4

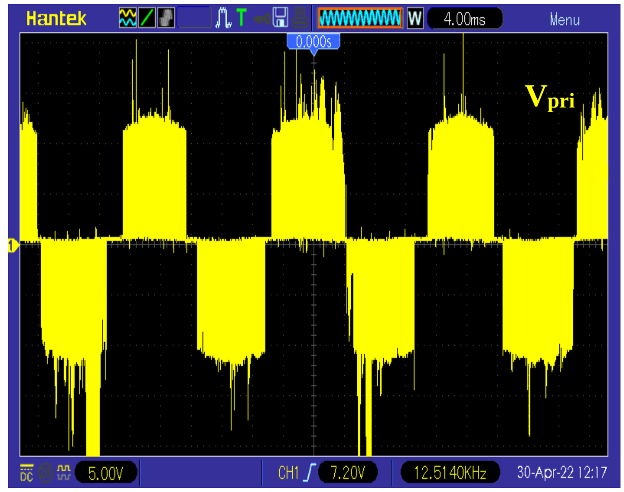

Fig.19: Transformer input voltage, V_{pri}

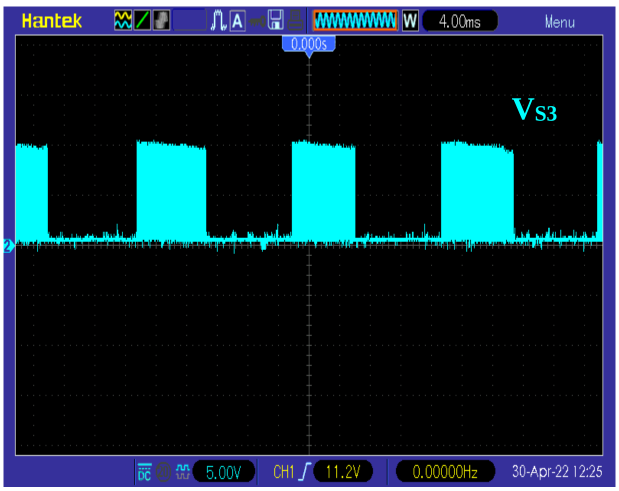

Fig.18: Power switch voltage across S_3.

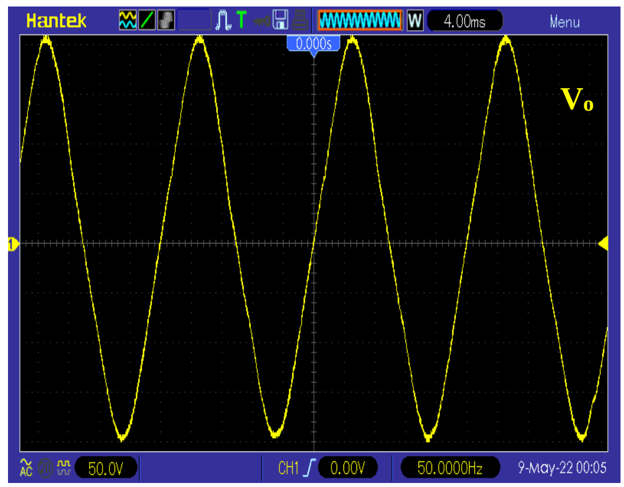

Fig.20: Filtered load output voltage, V_{Load}.

4. CONCLUSIONS

To develop a single-phase H-bridge inverter system using microcontroller is the major task of this paper. It is observed that the results from MATLAB/SIMULINK simulation agreed with the experimental results. The inverter system output frequency of 50 Hz, overall voltage THD found to be less than 4% is possible due to the controller board used. The control technique used for the inverter switches is sinusoidal pulse width modulation (SPWM) strategy. The control circuit unit using AT-MEGA 328 microcontroller is developed, as a result, the inverter system control circuit hardware is reduced both in size, weight and cost. The frequency/amplitude modulation ratios, dead time period and duty cycle can be easily change through programming without further hardware changes, if the microcontroller system is applied. The proposed inverter system finds good application in solar panel inverter powered system for domestic utilities.

5.0 Recommendation

Several possible extensions of this work are presented as (i) protection of the system from short circuit, (ii) development of non-transformer based inverter system, (iii) development of single to three phase system.

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References

Abhisek Maiti, Sumana Choudhuri, Jitendranath Bera, 2011. Development of Microcontroller based ISPWM Switching Technique for Single Phase Inverter. International Journal of Engineering Science and Technology (IJEST), 3(6), pp. 5298 – 5305.

Azuan A. 2007. Modeling and simulation of single-phase inverter with PWM using MATLAB/Simulink.UMP, MATLAB.

Dhambi Raj P and Murali Ganesh E., 2015. Study of Single Phase H-Bridge Inverter using Various Sinusoidal PWM Techniques. International Journal of Technical Research and Applications, 3(4), pp. 240 – 243.

Ghalib M. A., Abdalla Y. S., Mostafa R. M., 2020. Design and Implementation of Pure Sine Wave Single Phase Inverter for Photo Voltaic Applications. Available from: http: //www.researchgate.com

Hassaine L., Olías E., M Haddadi, Malek A., 2007. Asymmetric SPWM used in inverter grid connected. Revue des Energies Renouvelables. 10, pp. 421-429.

Ismail B., Taib S., Mohd Saad A. A., Isa M. & Hadzer M., 2006. Development of a Single-Phase SPWM Microcontroller-Based Inverter. First International power and Energy Conference PECon., 28 – 29 November, pp. 437-440.

Islam M. K., Haque F. and Islam N., 2019. A systematic Approach to Design Optimal Controller of Single phase VSC for distributed and Renewable Energy Application. 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT), 1(1), pp. 1-6.

Islam M. K., Raham M. M. and Rabbi M. F., 2015. Transformer less, Lower THD and Highly Efficient Inverter System. 2015 International conference on Advances in Electrical engineering (ICAEE), Dhaka, Bangladesh, pp. 293 – 296.

Lavenya K. and Umavathi M., 2022. Design and Analysis of Single-phase Inverter for Avionics System. In Book: Inventive Computation and Information Technologies, pp. 673 – 685.

Mamun A. A, Elahi M., Quamruzzaman M., Tomal M., 2013. Design and Implementation of Single Phase Inverter, International Journal of Science and Research (IJSR), 2, pp. 163-167.

Maurya P., 2014. Control Strategies of Inverter Using Wind Energy Conversion System For Variable Speed Application. International journal of collaborative research in engineering sciences, 1, pp. 1-6.

Meghriche M., Mansouri O., Cherifi A., 2006. Microcontroller-Based Single Phase Inverter Using a New Switching Strategy. IEEE Xplorer, pp. 14 – 16.

Kjaer S. B., Pedersen J. P., and Blaabjerg F., 2005. A Review of Single-Phase Grid- Connected Inverters for Photovoltaic Modules. IEEE Transactions on Industry application, 41(5), pp. 1292 - 1306.

Kerekes, T, Teodorescu, R, Rodríguez, P, Vázquez,G, Aldabas, E., 2011. A New High-Efficiency Single-Phase Transformerless PV Inverter Topology. Industrial Electronics, IEEE Transactions, 58(1), pp. 184-191.

Karshenas H. R. and Niroomand M., 2005. Design and implementation of a single phase inverter with sine wave tracking method for emergency power supply with high performance reference. 2005 International Conference on Electrical Machines and Systems, Nanjing, China, 2, pp. 1232-1237.

Parripati M. N. and Kirthika Devi V. S., 2020. A Single-Phase DC – AC Inverter for Aircraft Application. Fourth international Conference on Inventive Systems and Control (ICISC), IEEE Xplore Part Number:CFP20J06-ART; ISBN: 978-1-7281-2813-9, pp. 250 – 255.

Rahman K., Abu Tariq, Farhad Ilahi Bakhsh, 2012. Modeling and Analysis Performance Simulation Performance of Multilevel Inverter Using Bipolar and Unipolar Switching Schemes. IEEE-International Conference On advances in Engineering, Science and Management, pp. 466 – 471.

Rodney H. G. T., Chong B. C. and Sunil G. S., 2020. Modelling of single phase off-grid inverter for small standalone system applications. International Journal of power Electronics and Drive Systems, 11(3), pp. 398 – 1405.

Senthilkumar R. and Singgaaravelu M., (2010) "Design of Single Phase Inverter using dsPIC30F4013, International Journal of Engineering Science and Technology, Vol. 2, No. 11, pp. 6500 – 6506.

Shaaban A., Thomas J., Mostafa R., 2017. Design and Implementation of a Single Phase SPWM Inverter Based Microcontroller for wind Energy Conversion System. International Journal of Systems Applications, Engineering & Development, 11, pp. 291 – 296.

Sundas, H., Sohaib, A., & Muhammad, G., 2018. Design and Real-Time Implementation of SPWM based Inverter. 2018 International Conference on Engineering and Emerging Technologies (ICEET1), pp. 1-7.

Zope P. H., Bhangale P. G., Sonare P., el at., 2012. Design and Implementation of Carrier Based Sinusoidal PWM Inverter. International Journal of advanced research in electrical, electronics and instrumentation engineering, 1, pp. 230-236.