Microcontroller Based Pure Sine Wave Inverter

Conference Paper · March 2021

DOI: 10.1109/ICPEA51500.2021.9417841

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***Abstract*---The design of a microcontroller based pure sine wave single phase inverter is presented here. The system has an output of 220V and 50 Hz. The sinusoidal pulse width modulation technique has been used for the design. The circuit is simulated in Proteus to ensure the output results are verified practically. The experimental result shows a good argument with the simulation data. The inverter has fewer harmonics, is simpler to design compared to the traditional inverter technology. The designed inverter is tested on various AC loads and is essentially focused upon low power applications.**

Keywords--- Analog to digital converter (ADC), Harmonics, Inverter, Microcontroller, Sinusoidal Pulse Width Modulation (SPWM).

I. INTRODUCTION

Single-phase inverter is heavily used in home applications like uninterruptible power supplies (UPS), instant power supplies (IPS), induction heating, internet of things (IoT), renewable energy-based system. The input may come from a battery, rectified ac, fuel cell, solar cell, etc. It can be either standalone or grid-connected. Switch mode inverters are categorized mainly as a square wave and PWM inverters [1]. Square wave inverter is the simplest but comes with high harmonic contents close to the fundamental component. On the other hand, Sinusoidal Pulse Width Modulation (SPWM) scheme functions by comparing a modulating sinusoidal signal at desired output frequency with a high frequency (in kHz range) triangular signal acting as a carrier [2]. The advantage of this scheme is the shifting of harmonics at multiples of carrier frequency thereby making the output more sinusoidal than square wave inverter. Besides, this characteristic enables the use of smaller, cheaper filters as the higher frequency harmonics are easier to filter out.

In Bangladesh, most of the commercially available single-phase inverters in the marker are either square wave or modified sine wave inverters. These inverters are bulky, have high harmonic contents, and distorted outputs. The Total Harmonic Distortions (THD) of the output voltage for these square wave inverters are more than 30%. The loads connected to these inverters are affected due to the contents of the harmonic. The life cycles of these loads are reduced greatly by using this type of inverter. The few pure sine wave single-phase inverters available in the market are mainly used for special applications like datacenters and generally very expensive. Moreover, nowadays the Internet of Things (IoT) is becoming more accessible to general people and it will create a revolution in connectivity. Many works have been reported about this type of inverter [3]-[6]. These inverters have limitations like weighty, costly, and high harmonics contents. The inverter designed in [3] was designed for very low power application (16W) and have low output resolution. Both the inverters developed in [4] and [5] required high DC input voltage range (250-400V).This input voltage is difficult to implement and not suitable for low power applications like home, office, and datacenter. Moreover, the THD values of the output voltage of these inverters are also not reported. The inverter built-in [5] has been developed by multivibrator IC (NE 555),7^{th} order LCL filter, and open-loop system, which make the inverter bulky, costly, and less flexible. The inverter designed in [6] has been developed by the dc-dc converter, which makes the inverter bulky and costly. The inverters designed in [3-6] have not IoT feature.

A simple pure sine wave single-phase inverter with very low THD is presented here. The proposed method uses a 12V battery as an input, which is very common in the local market. To monitor and control the inverter, the IoT feature is also enabled in the proposed system.

II. SYSTEM DESIGN

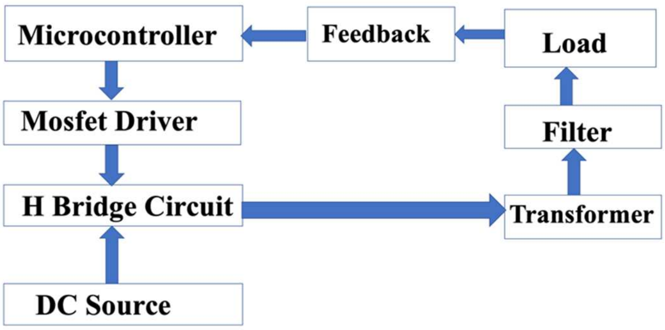


Fig. 1. Block diagram of Proposed System.

The block diagram of the proposed inverter is shown in Fig. 1. The system is controlled by a microcontroller. In the proposed sine wave inverter, an H-bridge driving configuration is used. There are four sets of switches connected like an H shape. Switching sequentially of these four switches can generate an alternating current flow through the load. An alternating current flow generates an alternating voltage across the load. If this load is a step-up transformer, an alternating voltage across the transformer's secondary is generated, which will be higher than the supply voltage. This is the basic configuration of the inverter. If this H-bridge is driven with an SPWM signal, an SPWM can be found on the transformer's higher voltage end. After filtering that, a pure sine wave is easily be found across the load. This is the concept of a sine wave inverter. Fig. 2 shows the circuit diagram of the inverter system.

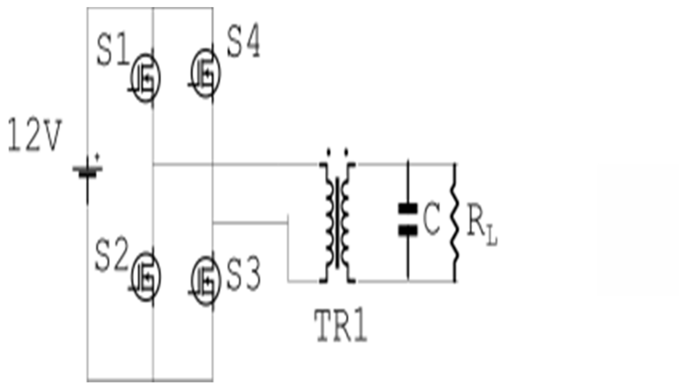


Fig. 2. The circuit diagram of single-phase inverter.

A. SPWM Generation

The main job of this inverter model is to generate SPWM using a PIC micro-controller. The PIC16F72 microcontroller does not have any special feature to generate SPWM. But it can generate PWM which is known as the CCP module of the micro-controller. In order to generate the SPWM signal, the duty cycle of this PWM signal is changed in a sinusoidal way, so that a pure sine wave is produced after filtering this signal. A lookup table is needed for this purpose. A open source software called "Smart Sine" is used to generate the lookup table.

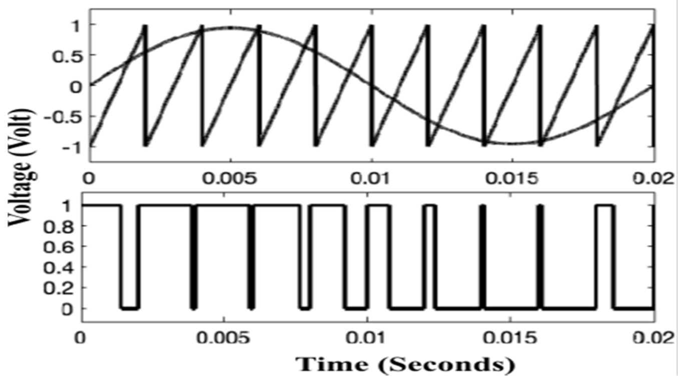


Fig. 3. SPWM generation technique.

There are no fixed numbers of samples for the sine table. Though a large number of samples produce a better resolution of the pure sine wave, they also consume more memory and demand high price microcontroller. The proposed system is designed by a sine table of 32 samples "unsigned char sin_table[32]={0, 25, 49, 73, 96, 118, 139, 159, 177, 193, 208, 220, 231, 239, 245, 249, 250, 249, 245, 239, 231, 220, 208, 193, 177, 159, 139, 118, 96, 73, 49, 25};" to generate the SPWM signal.

Since the system uses an 8-bit microcontroller, so the maximum value of 255 can be stored in the resister of this microcontroller. The system is also designed of using these 32 samples for half cycle of the desired 50 Hz signal. Timer2 module of this PIC16F72 has been used for this purpose, which generates a timer interrupt every 62.5 ms and the interrupt service routine of the program changes the duty cycle of the PWM incrementally according to the lookup table. Fig. 3 shows the SPWM generation.

The PWM signal frequency is set by using the PR2 register. In this system, the crystal oscillator frequency is 20 MHz, the prescaler value of Timer2 register is 16, and the SPWM frequency is taken as 20 kHz. From the following equation, the PR2 register value is obtained as 249. Fig. 4 shows the flowchart of SPWM generation for the PIC microcontroller.

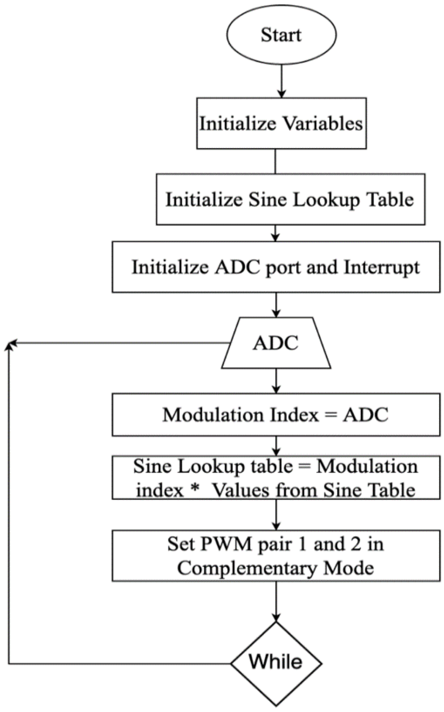
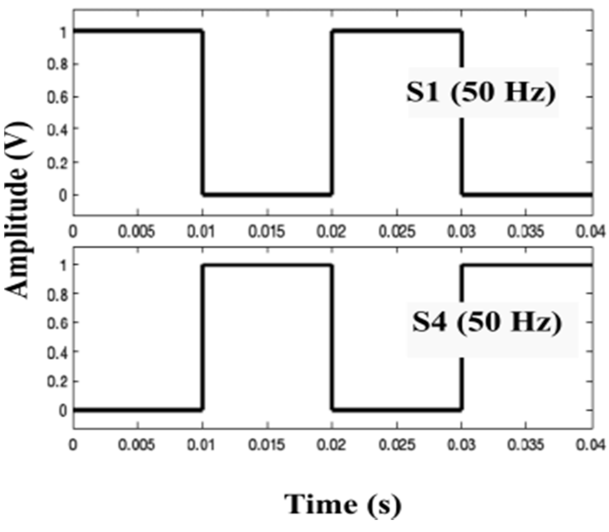


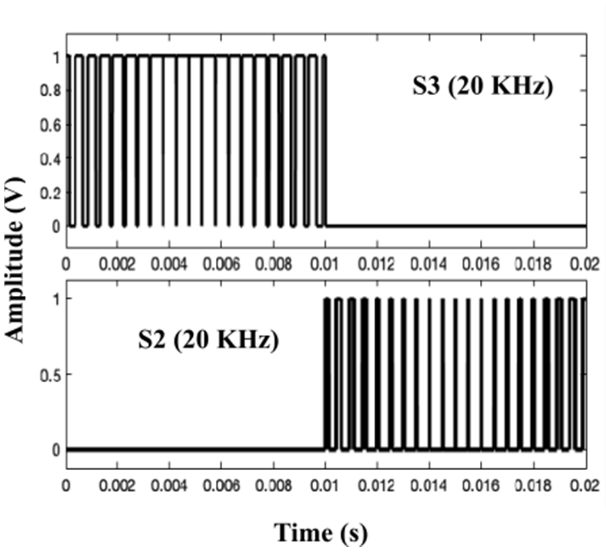
Fig. 4. Program flowchart for SPWM generation.

B. H-Bridge Circuit

An H bridge is built with four switches. To drive the H-bridge, four signals are needed. There are two signals (S1 and S4) at 50 Hz in a push-pull configuration, and the other two (S2 and S3) are SPWM signals (20 kHz). Fig. 5 shows the four signals. The upper arms of the bridge are switched by a 50 Hz signal, and the lower arms are switched by 20 kHz modulated signals. In the timer interrupt section, this timing and signal generation is done.



(a)



(b)

Fig. 5. Control signals of S1, S4 in (a) and S2, S3 in (b).

C. *Filter*

The MOSFETs are driving the main power transformer. The secondary terminal of this transformer is connected to a high voltage capacitor. The combination of this capacitor and the transformer (also an inductor) works as a filter.

D. *Feedback*

To regulate the output voltage, a feedback system is designed with a transformer, voltage divider, and utilization of the Analog to Digital Converter (ADC) module of the microcontroller. A feedback variable is used named 'fb_constant' in the program. This floating-point variable is used to reduce or increase the SPWM duty inside the timer interrupt. This makes a smooth feedback system for the sine wave inverter. The system uses a manual switch to turn the inverter on/off which is controlled by the variable 'inv_mask' inside the interrupt routine.

E. *IoT Feature*

The system is particularly designed for home, office, and datacenter applications. One of the great advantages of this proposed inverter system is no extra expensive Ethernet/LAN/GSM hardware module is installed for enabling IoT. The end device is connected with the inverter by USB to TTL converter. IoT feature is availed by utilizing the (Universal Asynchronous Receiver / Transmitter) UART module of the microcontroller and PySerial library of Python programming language. The Graphical user interface (GUI) is designed in Flask, which is a very popular micro web framework work written in Python language. The Flask webserver was running at port 80 of the client machine. In this experiment, a raspberry pi was chosen for the client machine.

Since the software is written in python language, the software will be portable means it can run on the different operating systems on computers, servers, and raspberry pi. This inverter can be remotely monitored and controlled using the client machine (computer, server, or raspberry pi) IP address. The proposed system is tested in a private network, where its IP address was 10.20.100.5/24. Instead of costly public IP address allocation, the router's port forwarding option was allowed at port 8080 to access this inverter from the internet. In this experiment locally purchase Wi-Fi router, tp-link TL-WR940N was used.

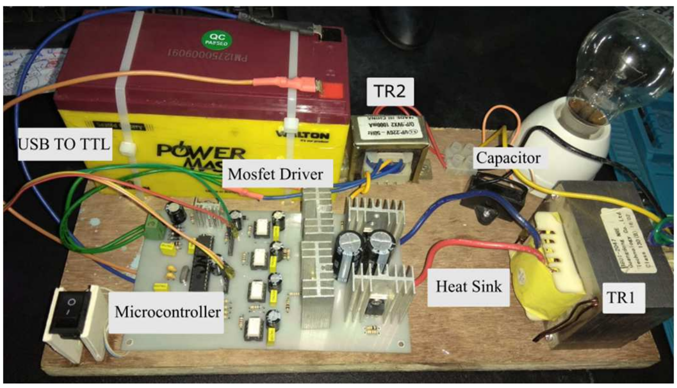
III. HARDWARE SELECTION & IMPLEMENTATION

A. *Gate Drivers*

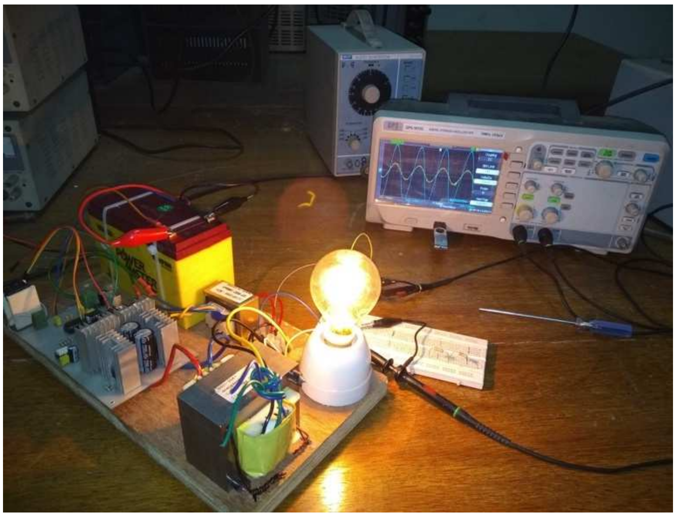
An H bridge is built with four switches. These four signals cannot be directly used to switch the MOSFETs. The Gate driving circuits are needed to convert the signal from the micro-controller to switch MOSFET. These gate driving circuits simply convert the MCU's 5V signal into a 10V+ signal which can be used to switch MOSFETs. The MOSFET driver TLP250 is used to apply the switching pulses coming from the microcontroller to the MOSFET switches. The great feature of this IC is that it provides two features in one IC; opto-isolator and gate driver feature. The input and output of TLP250 MOSFET driver are isolated from each other. Its works like an optocoupler. Heat sinks are also provided to protect MOSFET from overheating. Fig. 6 shows the hardware selection and implementation of the proposed inverter system.

B. *Transformer & Capacitor*

The system uses a low pass LC circuit. The power transformer (TR1) has trans-ratio (7.5:240), which is popularly known as UPS transformer, acts as an inductor, and a 1.5uF high voltage electrolytic capacitor is used for filtering purposes. A center-tapped step-down transformer (TR2) with 12V output is used for feedback purposes.



(a)

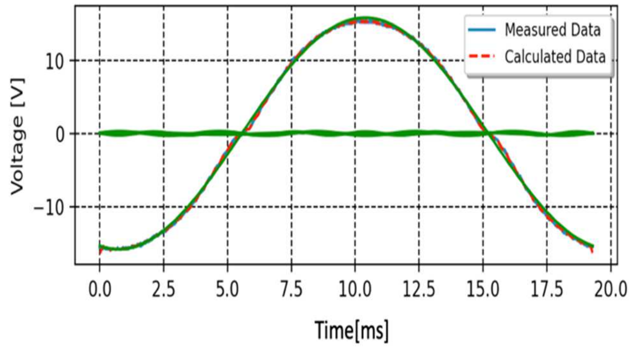


(b)

Fig. 6. Hardware selection (a) and implementation (b).

IV. EXPERIMENTAL OBSERVATION

The developed inverter is tested experimentally for different loads and different input and output parameters are measured. Fig.7 shows the output voltage and current curves obtained experimentally by using a digital oscilloscope for 60W load. The output voltage and current of the inverter are recorded in CSV format from a digital oscilloscope for calculating THD measurement for different loads. By using CSV files, output wave shape and THD value can be calculated from Python programming language. Fig. 8 shows the harmonics of output voltage and current of the inverter for 60W load. The calculated output waveform from MATLAB and oscilloscope output waveform is identical, which verifies our experiment result. Due to the feedback mechanism by utilizing ADC of microcontroller, voltage regulation of inverter is better than traditional inverter circuit. When its output voltage falls below the predefined value, then the microcontroller is scaling up all the 32 samples of duty cycles according to the calculated modulation index value. The efficiency of the inverter from 60W to 150W loads is varying a little (72% to 80%). The measurement of the total harmonic distortion of the output voltage is also satisfactory (around 2%). Table I shows the detailed practical results for different load conditions. The SPWM frequency greatly reduces filter size and cost. Table II shows the necessary building components list with the cost. Table II is also a justified cost-effective feature of the proposed inverter design. Locally available inverters have almost three times more expensive than the proposed inverter model. Though the efficiency of the inverter is low, its output waveform is a pure sine wave. The transformer used in this experiment has high no-load losses and copper losses. The core of this locally purchased transformer has low quality. This attributes to the lower efficiency of the inverter around 80%. Fig. 9 shows the IoT feature of the proposed inverter system.



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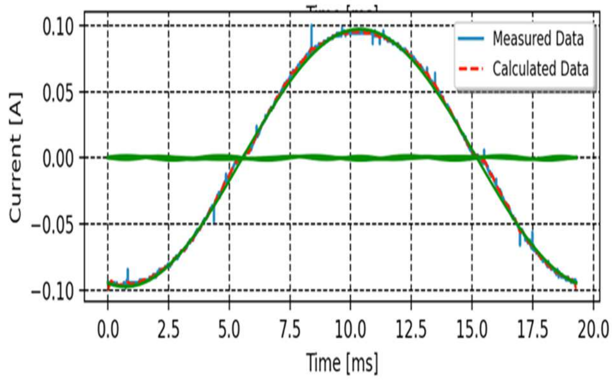
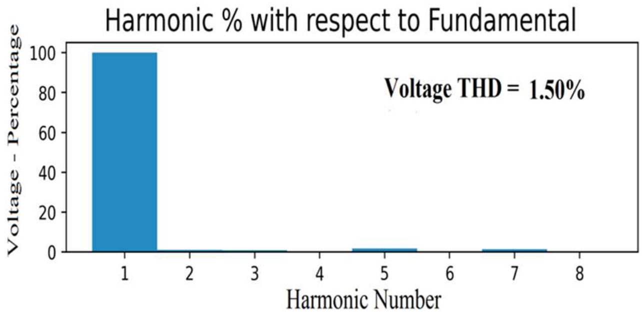
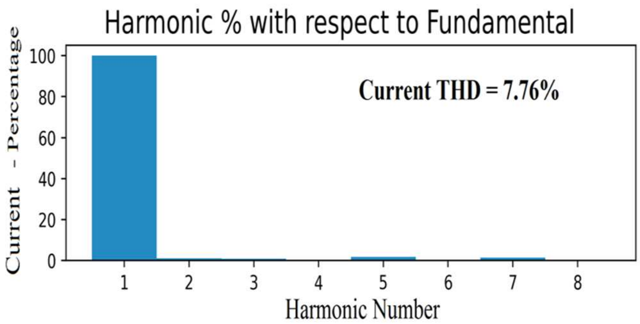


(b)

Fig. 7. Measured output parameters of the inverter (a) voltage (b) current.



(a)



(b)

Fig. 8. Harmonics of the output parameters of the inverter (a) voltage (b) current.

TABLE I: Experimental results of the inverter for different load conditions

Load	η	V_{THD}	I_{THD}	V_{in}	I_{in}	V_{out}	I_{out}
60W	76%	1.50%	7.76%	11.80	4.63	203	0.20
100W	80%	2.11%	9.20%	10.94	6.58	178	0.33
120W	78%	2.05%	7.18%	10.66	7.04	162	0.37
150W	72%	2.14%	6.91%	10.53	8.80	158	0.42

TABLE II: Components price list

Component	Quantity	Price (Tk)
Microcontroller (PIC16F72)	1	120
MOSFET Driver (TLP250)	4	320
MOSFET (IRF 3205)	4	160
DC link capacitor (6600uF)	1	40
AC Filter capacitor (1.5uF)	10	10
Power Adapter	1	190
Transformer (7.5:240)	1	1200
USB to TTL Converter	1	250
Others	-	210
	Total	2500

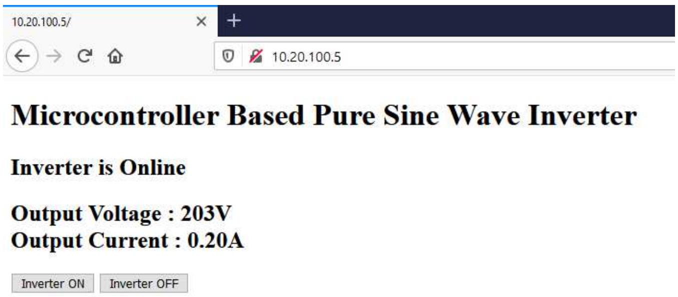


Fig. 9. IoT feature of the system.

V. CONCLUSION

A single-phase SPWM based pure sine wave inverter has been simulated, developed, and tested practically successfully for a maximum load of 150W. Due to the feedback control system, voltage regulation is better and efficiency is also found to be satisfactory. Due to the high switching frequency, the THD of output is also decreased. Lower THD, small size, simple control architecture, and cost of the proposed inverter are verified its omnipresent in the near future. Reduction in high copper and core losses in low-frequency transformers would lead to better efficiency. The proposed control algorithm is very easy to deploy in any low-cost single-chip microcontroller-based system. This inverter model can easily be deployed in the current smart-home; peer-to-peer electricity sharing architecture based micro grid system.

ACKNOWLEDGMENT

The authors would like to acknowledge the opportunity and the infrastructural support provided by the Department of Electrical and Electronic Engineering of Bangladesh University of Engineering and Technology (BUET) to carry out this research.

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