Modeling of a Pure Sine Wave Power Inverter using Sinusoidal Pulse Width Modulation (SPWM) Technique

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Abstract:- Over the years, renewable energy has gained a lot of popularity in Nigeria, and Africa as a whole. Power electronics and converter systems play an important role in the renewable energy sources analysis and modeling. This work provides a discrete modeling and design method for digitally controlled inverters using software based generation of sinusoidal pulse width modulation. We introduce the background and foundations of power inverter digital control. For digital pulse-width modulations (PWMs) with delay effects, small-signal models are developed. The controllers can be designed using a variety of models in accordance with the block diagrams based on the models. The experimental setting and simulation software for the digitally controlled inverters are then described.

Keywords:- *Inverter, Pure Sine (PS) wave, Nigeria, Uninterruptible Power Suppliers, Proteus, c++ program, Arduino.*

I. INTRODUCTION

Direct current (DC) and alternating current (AC) are the two basic types of electrical power. Direct current has the advantage of being able to be stored in batteries, but alternating current can have its voltage level changed by using transformers.

In developing countries, shortage of power is a problem commercially and domestically [1]. Existing electricity production sources are under a heavy pressure from newly constructed offices. The situation, particularly in some urban areas, worsens when the quickly rising private and domestic demand is added. Simply put, we are becoming more able to consume energy than we are to produce it. Under these circumstances, failure will happen suddenly and without notice as a result of strains on the insufficient power sources. The necessity for an alternate energy source that can bridge the gap and cover power supply gaps results from this. Overcoming this obstacle led to the application of DC/AC power inverters. Short term solution of power disruption could be addressed through the use of these inverters and a source of DC power.

An inverter is an electrical system that converts direct current (d.c) power into an alternating current (a.c) [2]. Components, such as but not limited to transistors, resistors, diodes, relays, rectifiers, and switches, can be used to carry out the inverting operation. Wherever there is a requirement to maintain a. c. power in a building or residence, an inverter can be found.

II. LITERATURE REVIEW

The adoption of solar-inverter systems among Nigerians has likely increased over time, making it one of the country's most prevalent sources of alternative energy at the moment. Also produced locally are inverters by businesses and individuals. [3].

There are three major inverter waveform types, Square wave, Modified Sine (MS) wave, and PureSine (PS) wave. Of these, only the last two are commonly seen, as the square wave is considered obsolete. Modified Sine (MS) wave and Pure Sine (PS) wave generators are the two main power inverter types available on the Nigerian market today. The outputs of these inverters vary, offering various degrees of efficiency and distortion that might have diverse effects on electrical equipment. A MS wave is similar to a square wave but instead has a “stepping” look to it that relates more in shape to a sine wave [4]. An approximation of a sine wave may be created by outputting one or more stepped square wave with the amplitudes chosen to approximate the sine [5]. This can be seen in Fig. 1, which displays how a MS wave tries to emulate the sine wave itself. Notice that as time progresses from left to right, the two different waveforms rise at different rates. The MS waveform is simple to create because it only requires switching between three values at predetermined frequencies, omitting the more intricate circuitry required for a PS wave. The MS wave inverter offers a simple and affordable method for powering AC-required devices.

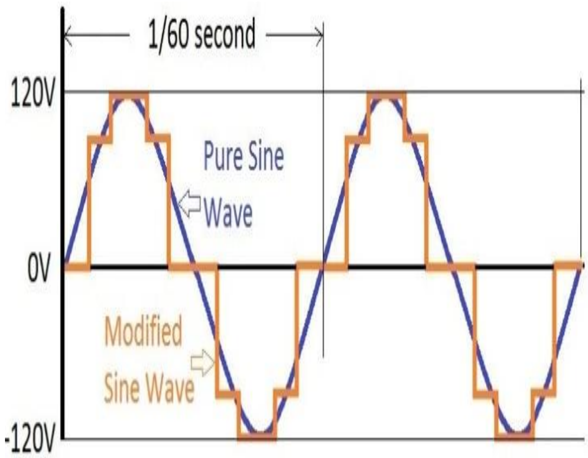

Fig. 1: Modified sine wave and pure sine wave

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The inverters constructed in Nigeria which is available commercially and also those incorporated in UPS (Uninterruptible Power Suppliers) are mostly MS wave inverters which are not suitable for sophisticated electrical devices and equipments in daily use due to their output waveform which constitute of undesirable harmonics [6], [7].

The modified sine wave is made up of several sine waves with odd harmonics (multiples) of the modified sine wave's basic frequency. A modified sine wave at 60 Hz, for instance, will include sine waves with odd harmonic frequencies like the third (180 Hz), fifth (300 Hz), seventh (420 Hz), and so on. A modified sine wave's high frequency harmonic content increases radio interference, increases the heating effect on motors and microwaves, and causes overloading by lowering the impedance of low frequency filter capacitors and power factor improvement capacitors [8].

A. *Need for the Research*

A sine-wave inverter's output voltage has a sine waveform similar to the sine waveform of the mains/utility voltage. In a sine wave inverter, the voltage rises and falls gradually, the phase angle changes gradually, and the polarity changes instantaneously when the voltage reaches 0 volts. In a modified sine wave, the voltage rises and falls sharply, the phase angle also shifts sharply, and it remains at 0 Volts for some time before switching polarities. Therefore, any device that uses a control circuitry that senses the phase (for voltage/speed control) or instantaneous zero voltage crossing (for timing control), will not work properly from a voltage that has a modified sine wave-form [6].

Having observed the need for producing inverters that can be used to operate sensitive electronic devices that require high quality waveform with little harmonic distortion, there is need to establish a proper study on modeling and production of a pure sine wave inverter using simple methods and readily available materials. This can serve as a tool or guide to Nigerian engineers in the future.

B. *Significance of the Research*

➢ *Same Current as Power Grids*

A pure sine wave inverter produces a wave that is very similar to the smooth wave form generated by mains electricity. That is, there is no discernible difference between plugging your devices into these inverters and plugging them into a wall outlet with power supply from the public power supply.

➢ *Minimal Risk to Devices*

The smooth wave form produced by a pure sine wave inverter also protects your high-end electronics from damage during power outages. Using modified sine wave inverters with AC-powered devices such as microwaves and refrigerators can generate excessive waste heat, putting your devices at risk. Pure sine wave inverters, on the other hand, pose no threat to any of your devices.

➢ *Quiet Operation*

Pure sine wave inverters reduces audible and electrical noise in fans, fluorescent lights, audio amplifiers, TV, fax and answering machines.

➢ *Compatibility with a Wide Range of Devices*

Inductive loads like microwave ovens and variable-speed motors operate properly, quieter and cooler. Some appliances will not produce full output if they do not use Sine-Wave power.

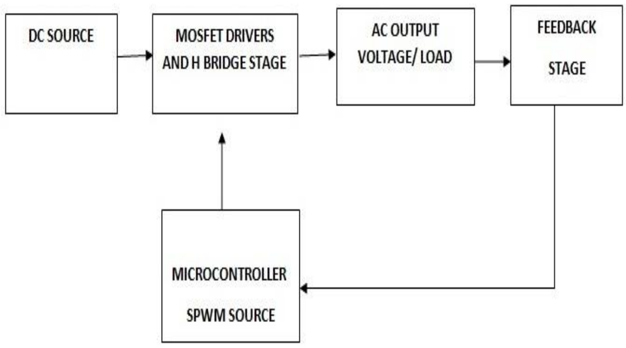

Fig. 2: Blocks Diagram of Pure Sine Wave Inverter

III. MODELING A PURE SINE WAVE INVERTER USING SOFTWARE GENERATED SMALL SIGNAL SINUSOIDAL PULSE WIDTH MODULATION

As power inverters are usually implemented by using H bridges, describing the output voltage of H bridges as a function of the modulation signal is required. The transfer function of Pulse Width Modulation (PWM) model varies when different carriers and modulation techniques are used [9]. The typical circuit diagram of an H bridge is shown in Fig. 3. The output of the H bridge is the filter input voltage v_{in}. The switching output is defined as $y = v_{in}/V_{dc}$. The switching output varies significantly when different modulation strategies are used.

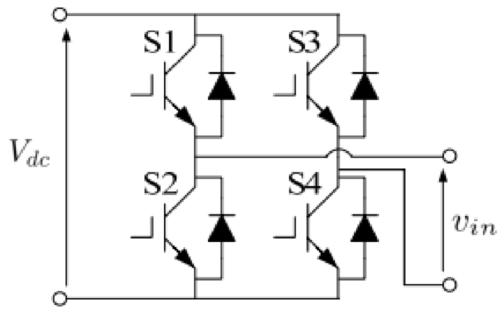

Fig. 3: A typical H bridge circuit

If there are two voltage levels produced on the switch voltage Vin, i.e., Vdc and −Vdc, the H bridge is bipolar switched. In order to provide the model for a single-update-mode bipolar switched H bridge, we assume that the duty-ratio is updated at each sampling instant. Therefore, the Digital Signal Processor (DSP) delay is one sampling cycle. When the sampling frequency is equal to the switching frequency, the key waveforms of bipolar switched H-bridge are shown in figure 4.

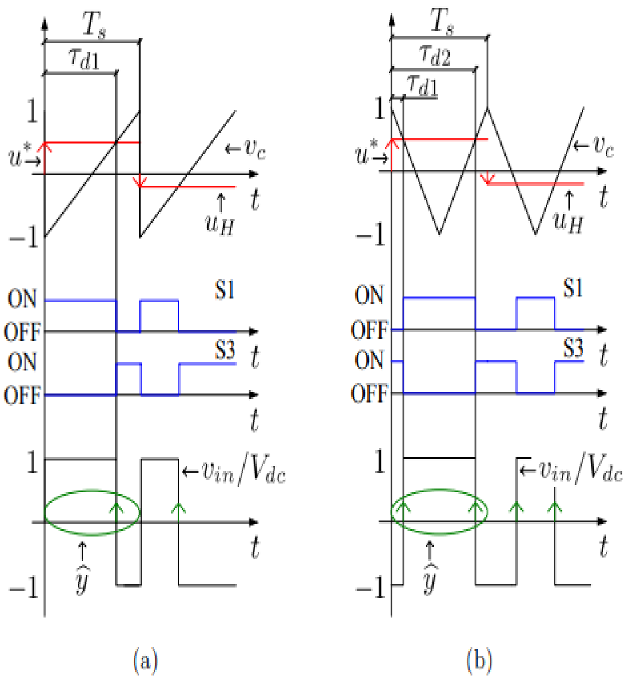

Fig. 4: Key waveforms of single-update-mode uniformly-sampled bipolar switched H-bridge. (a) End-of-on-time modulator. (b) Symmetric-on-time modulator.

It can be seen from Fig. 4 that the filter input voltage frequency of the bipolar switched H-bridge is equivalent to the switching frequency. The duty ratio can be updated only once when using saw-tooth carriers. However, for triangle carriers, the duty-ratio can be updated twice a switching cycle. As the DSP delay from $x*$ to $u*$ is Ts, the small-signal transfer function describing yb as a function of xb $*$ for end-of-on-time modulator is written as:

$$G *_{pwm(s)=TSe^{-s(1+D)Ts}} \tag{3.1}$$

On the other hand, for symmetric-on-time modulator, the small-signal transfer function $G *_{pwm(s)}$ can be expressed as

$$G *_{pwm(s)=\frac{Ts}{2}(e^{-s\frac{(3-D)Ts}{2}}+e^{-s\frac{(3+D)Ts}{2}})} \tag{3.2}$$

For bipolar switched H bridges, each switching cycle contains two updated samples with two relevant switching actions. If the sample is updated at the upper peak of the carrier, the delay from $* \; to \; y \; is \; \frac{(1-D)Ts}{2}$. On the other hand, if the sample is updated at the lower peak of the carrier, the delay from $u*$ to yb become $\frac{DTs}{2}$. During each switching cycle, the possibilities of the two situations are equal. As the exact analytical expression of the double-update-mode PWM model is not easy to obtain, the approximation can be applied by averaging the two delay effects. With half switching cycle DSP delay from $x*$ to $y*$, the double update-mode PWM model of the bipolar switched H-bridge is given by

$$G *_{pwm(s)=\frac{Ts}{4}(e^{-s(2-D)Ts}+e^{-s(1+D)Ts})} \tag{3.3}$$

IV. SIMULATION

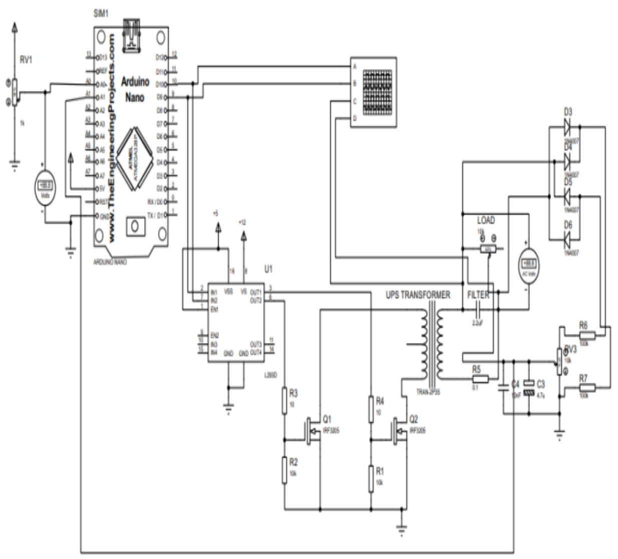

Fig. 5: Proteus simulation diagram

The simulation work of this research is implemented in Proteus. The digital controllers can be built up by commonly used classic Proteus models. Then, a c++ program is loaded into the controller to model both the switching and carrier frequency. This frequency is fed into the H-bridge to be stepped up to 230V AC.

- **INPUT STAGE:** The input unit consists of sinusoidal pulse width modulation generation from the arduino nano microcontroller using a c/c++ program. When simulated it could be seen that the two SPWM signal are complementary, which connotes that they are 180 degrees half phase.

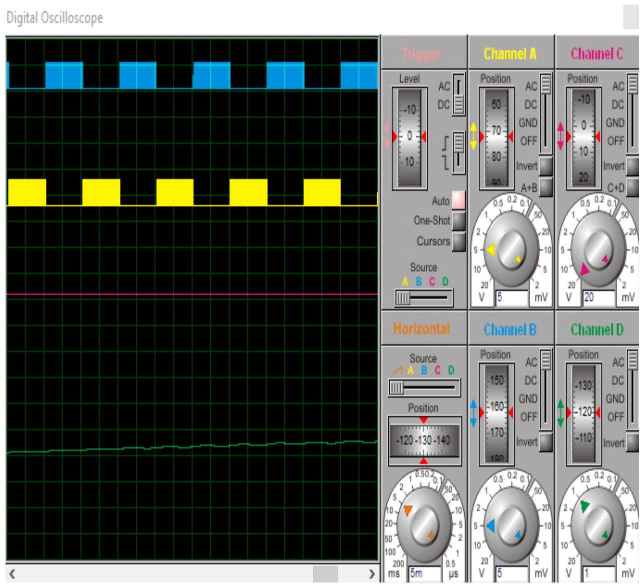

Fig. 6: Simulated digital small signal of sinusoidal PWM voltage

- **OUTPUT STAGE**: It consists of the final pure sine wave inverter signal. During the test, it can be seen that there were less harmonics on the sine wave because of the inclusion of the LOW pass filter.

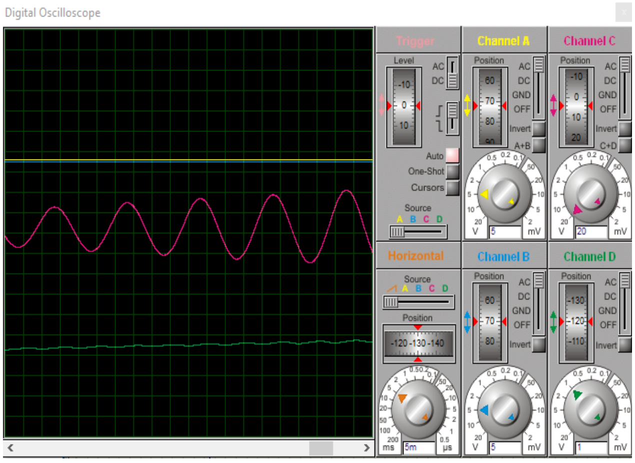

Fig. 7: Simulated output voltage

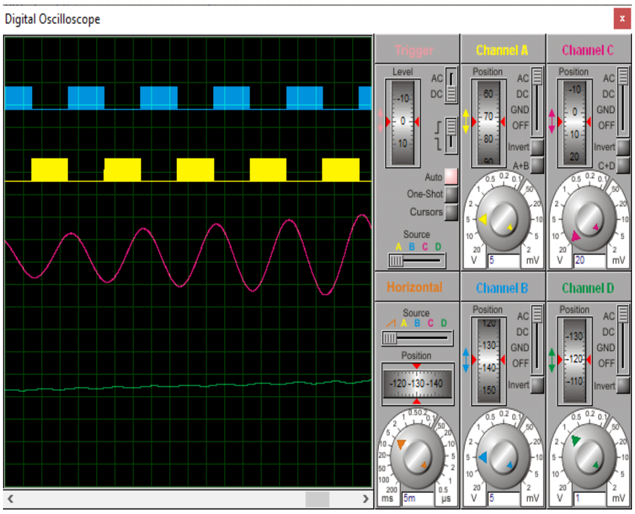

Fig. 8: Simulated digital small signal SPWM at MOSFET driver and the output voltage

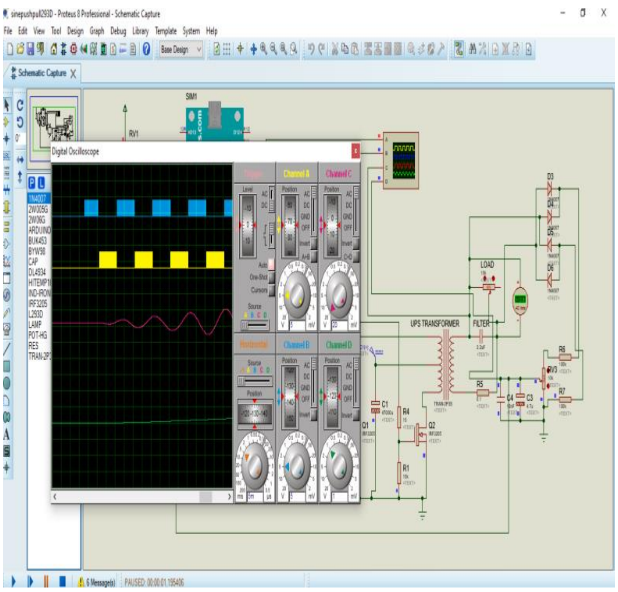

Fig. 9: The simulation environment in Proteus software

V. APPLICATION

The microcontroller used is ATmega328 in Arduino nano board. This is shown figure 10 below.

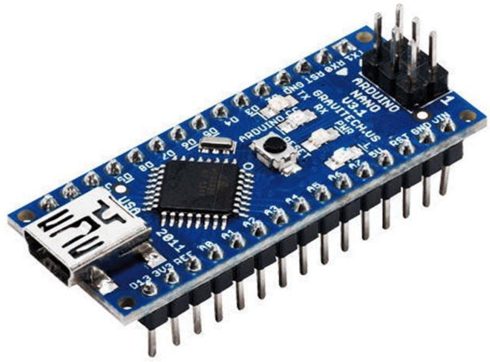

Fig. 10: Arduino nano

VI. TESTING THE MODELED PURE SINE WAVE INVERTER IN PROTEUS

The Arduino software can be used to program an Arduino nano. Select the nano board by clicking the Tools option. The boot loader for the ATmega328 microcontroller on the Nano board is preprogrammed. With the help of this boot loader, fresh code can be uploaded without a third-party hardware programmer. This can be communicated with via the STK500 protocol. Here, the boot loader can also be disregarded, and the microcontroller software can be executed using an Arduino ISP and the in-circuit serial programming (ICSP) header.

The program is written in C/C++ programming language. The program is written to generate a small signal SPWM at its output which is interfaced to H bridge stage of the inverter. The program is compiled using Arduino integrated development environment (IDE) and exported as Hex file. This hex file is imported into the proteus software on the microcontroller model we used. The simulation will not run if there is no code on the microcontroller. Hence, with the code imported, simulation can commence.

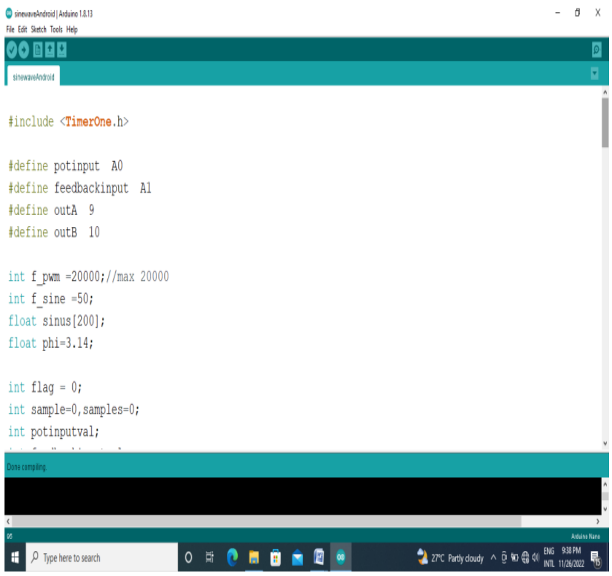

Fig. 11: Arduino IDE

The simulation diagram in figure 5 is replicated in real life with the H bridge (four MOSFET connected in H topology) and the step up transformation stage. Of course, the filter stage removes the harmonics on the sinusoidal waves. The complete program for the simulation is shown in appendix A.

VII. CONCLUSION

Although there has been a lot of progress in the field of pure sine wave inverters, the difficulty of producing a waveform with low harmonic content and good efficiency remains. There are methods for doing this, but it is necessary to adopt one that is also simple to produce and use, especially for low power applications. This study analyzed existing methodologies and attempted to develop a low power application solution that is simple to deploy, affordable, and reliable from the consumers' point of view once implemented. We have made an effort to develop an inexpensive design for low power applications.

This research draws the conclusion that this method is an affordable, adaptable, and effective way to design pure sine wave inverters.

VIII. APPENDIX A

```
#include <TimerOne.h>
#define potinput  A0
#define feedbackinput  A1
#define outA  9
#define outB  10

int f_pwm =20000;//max 20000
int f_sine =50;
float sinus[200];
float phi=3.14;

int flag = 0;
int sample=0,samples=0;
int potinputval;
int feedbackinputval;
int A;
int max_power=800;//max 1023
float invert=0.0;
int total_sample;
int phase =0,x=0;

void setup() {
  total_sample
=round((((1000000./f_sine)/(1000000./f_pwm))/2.));
  for (int sudut=0;sudut<total_sample;sudut++)
  {
    float rad= sudut*(180./total_sample)*phi/180;
    sinus[sudut]=sin(rad);
  }

  float t_pwm=(1000000./f_pwm);
  delay(1000);
  pinMode(potinput, INPUT);
  pinMode(feedbackinput, INPUT);
  pinMode(LED_BUILTIN,OUTPUT);
  A = 0;
  Timer1.initialize(t_pwm);
  Timer1.attachInterrupt(generate_sinus);
  //samples=(total_sample*2/3);
Timer1.pwm(outA,(sinus[sample]* A));
Timer1.pwm(outB,(sinus[sample]* A));
  }
  void loop() {
   potinputval = analogRead(potinput);
   feedbackinputval = analogRead(feedbackinput);
    while (feedbackinputval < potinputval  ) {
     if (A >= max_power) {
       potinputval = analogRead(potinput);
       feedbackinputval = analogRead(feedbackinput);
      }
     else {
       A = A + 1;
       potinputval = analogRead(potinput);
       feedbackinputval = analogRead(feedbackinput);
     }
   }
   while (feedbackinputval>potinputval ) {
     if (A == 0) {
       potinputval = analogRead(potinput);
       feedbackinputval = analogRead(feedbackinput);

     }
     else {
       A = A - 1;
       potinputval = analogRead(potinput);
       feedbackinputval = analogRead(feedbackinput);
     }
   }
 }

void generate_sinus(){
generate();
 }

 void generate(){

   if(sample>=total_sample && flag==1  ){
       flag=0;
       sample=1;
       //TCCR1A=0b10100000;

     }

        if(sample>=total_sample && flag==0){
       flag=1;
       sample=1;
       //TCCR1A=0b10100000;;
     }
     sample++;
     if(flag==0){
        Timer1.pwm(outA,(sinus[sample]* A));
        //PORTB=(0<<PORTB3);
        Timer1.pwm(outB,0);
     }
     if(flag==1){
        Timer1.pwm(outA,0);
```

```
        //PORTB=(1<<PORTB3);
        Timer1.pwm(outB,(sinus[sample]* A));

      }
    }
```

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