# Microcontroller Based SPWM Single-Phase Inverter For Wind Power Application

Khin Ohmar Lin, Hla Myo Tun, Zaw Min Naing, Win Khine Moe

**Abstract:** In this paper, microcontroller based sinusoidal pulse width modulation (SPWM) single-phase inverter is emphasized to constant frequency conversion scheme for wind power application. The wind-power generator output voltage and frequency are fluctuated due to the variation of wind velocity. Therefore, the AC output voltage of wind-generator is converted into DC voltage by using rectifier circuit and this DC voltage is converted back to AC voltage by using inverter circuit. SPWM technique is used in inverter to get nearly sine wave and reduce harmonic content. The rating of inverter is 500W, single-phase, 220V, 50 Hz. The required SPWM timing pulses for the inverter are generated from the PIC16F877A microcontroller. Circuit simulation was done by using Proteus (7 Professional) and MATLAB(R 2008) software. The software for microcontroller is implemented by using MPASM assembler.

**Index Terms**: Microcontroller, SPWM, single-phase inverter, wind-power generator, PIC16F877A

## 1 Introduction

In the clean, cheap, safe, and renewable energy sources, wind power is one of the most attractive solutions. In the past wind power was used for several countries for propelling ships, pumping water, irrigation fields, driving wind-mill such as grinding flour mills, wood cutting saws, stone crushers, mixers and other purposes. The exploitation of plenty of cheap fossil fuels and development of internal combustion engines have led to the wind power being gradually replaced by other energy sources during the first half of twenty century. Now, the oil crisis with environmental consciousness has renewed the interest in the wind power all over the world. But the limitation of wind system is that the velocity of wind is variable unsteady and irregular. So the wind turbine speed is variable and the output frequency and voltage of the wind-generator is fluctuated. Therefore, power electronic converters are used to get constant frequency and constant voltage at the output side. Recent advances in thyristor inverter technology have paved a way for variable speed constant frequency systems (VSCF). Fig.1 shows a block diagram of VSCF. The wind turbine is with variable speed. The rotor speed is allowed to vary optimally with the wind speed. The rectifier-inverter combination delivers constant frequency electrical output which can be delivered to the load or the grid. Variable speed wind turbine requires simpler wind turbine and its controls. There is no need of pitch control. The wind energy is optimally utilized. The turbine always works with maximum efficiency. Due to variable speed, the stresses on wind turbine rotor, blades are reduced greatly. Recent large wind turbine generator units are variable speed constant frequency system [1].

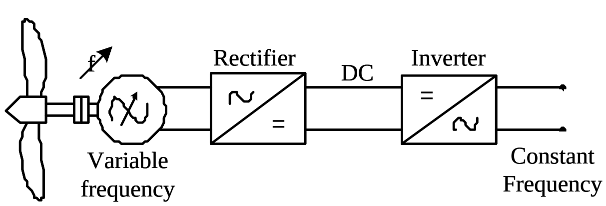


***Fig. 1.*** *Variable speed constant frequency system [1]*

The types of inverters are classified according to number of phases, use of power semiconductor devices, and the shape of output waveform. Ideal output waveform of inverter is sine-wave. But, the inverters available in market are square wave and step sine wave. Those types of inverters have higher harmonic content and voltage distortion. In SPWM inverter, the output waveform is nearly sine wave and requires small filter size to eliminate the harmonic content.

## 2 Derivation of PWM

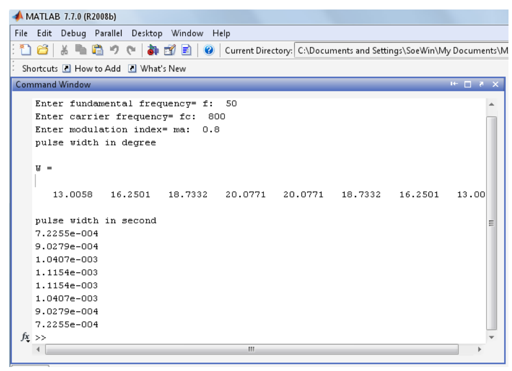


***Fig. 2.*** *Pulse widths calculation in MATLAB*

The pulse width $W_2$ is determined by the following equation.

$$\frac{2W_2 - L}{L} = M\cos\alpha_2 \quad (1)$$

In general,

$$\frac{2W_n - L}{L} = M\cos\alpha_n \quad (2)$$

where, s = number of pulses per half-cycle

$$= \frac{\text{carrier frquency}(f_c)}{\text{reference sine frequency}(f)}$$

L = 180 degree/ s
W = pulse width
M = modulation index (0 to 1)

$$= \frac{\text{ampitud of reference sine wave}}{\text{amplitude of carrier triangle wave}}$$

α = pulse centre angle

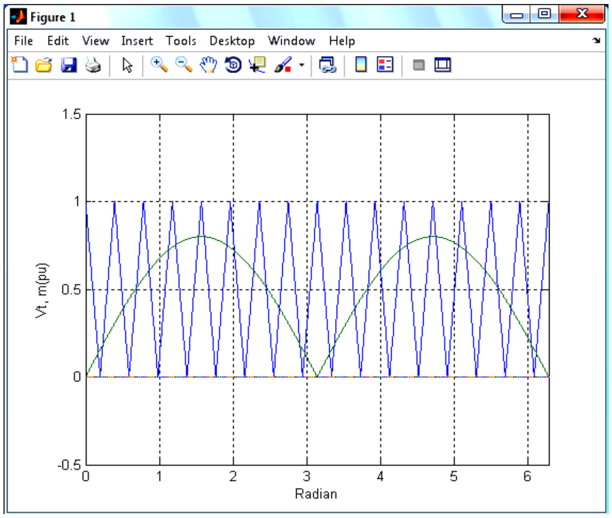


***Fig. 3.*** *Sine wave and carrier triangle wave comparison*

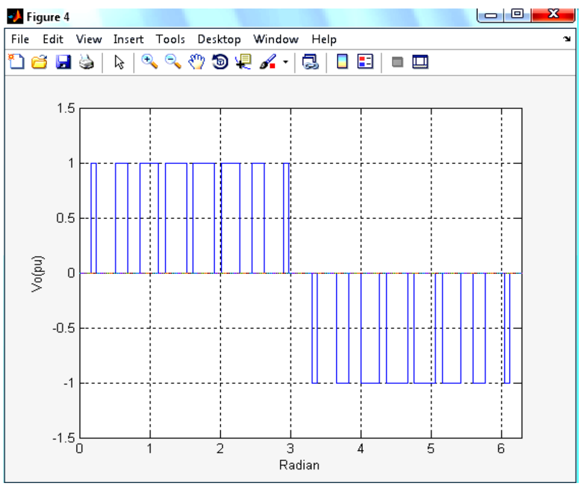


***Fig. 4.*** *The per-unit output waveform of SPWM inverter*

A strategy for realising the switching instants of the inverter so that the pulse width in each interval is in conformity with equation (2) will be the key to the practical implementation of SPWM. Fig. 4 shows the pulse widths calculation for s = 8, M = 0.8, $f_c$ = 800 Hz, f = 50 Hz by using equation (2) in MATLAB command window. The reference sine wave and carrier triangle wave comparison is shown in fig. 3 for per-unit basic. The per-unit SPWM waveform is shown in fig. 4. Owing to the symmetries in the PWM waveform of fig. 5, only the odd harmonics exist. Assuming that the PWM waveform is chopped n times per half a cycle, the Fourier coefficients of odd harmonics are given by;

$$V_k = \frac{4E}{k\pi}\,[\cos k\alpha_1 - \cos k\alpha_2 + \ldots + (-1)^{j-1}\cos k\alpha_j + \ldots + (-1)^{n-1}\cos k\alpha_n] \quad (3)$$

where k= 1, 3, 5, … and E is the amplitude of the square wave.

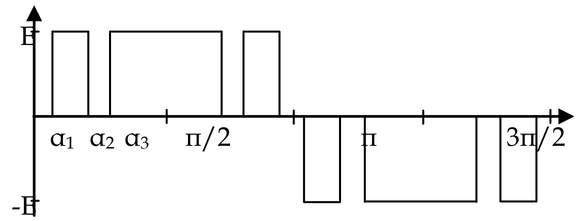


***Fig. 5.*** *A three-level PWM waveform [5]*

Amplitude of n harmonics can be set by solving a system of n nonlinear equations obtained from setting equation (3) equal to pre-specified values. In the harmonic elimination programmed SPWM method, the fundamental component is set to required amplitude and n-1 low-order harmonics are set to zero. Fig. 6 shows the harmonic contents in SPWM in modulation index=0.8, carrier frequency=800Hz, reference frequency=50 Hz.

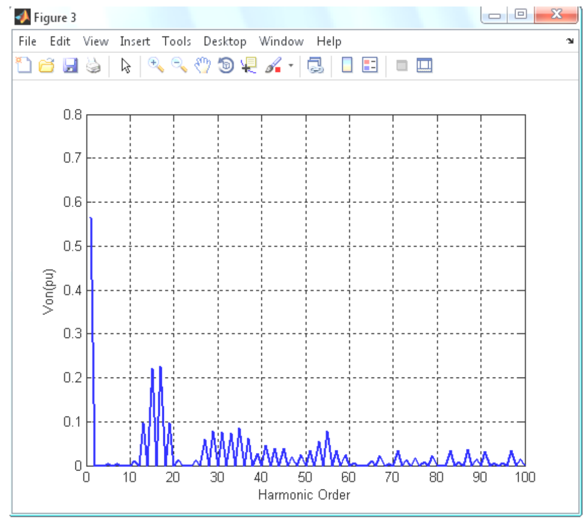


***Fig. 6.*** *Harmonic in SPWM (M=0.8, $f_c$=800 Hz, f=50 Hz)*

## 3 Switching Inverter

An inverter converts from a DC input into AC output statically. The inverter also has a switching control circuit that provides the necessary pulses to turn ON and turn OFF each switching element with the correct timing and sequence. These switches are repetitively operated in such a way that the DC source at the input terminal of the converter appears as AC at the output terminals. The block diagram of inverter is shown in fig. 9. The main parts of inverter are mentioned as the following:

(i) Switch mode power supply
(ii) Microcontroller
(iii) MOSFETs driver circuit
(iv) H-bridge MOSFETs
(v) Step-up transformer, and
(vi) Harmonic filter

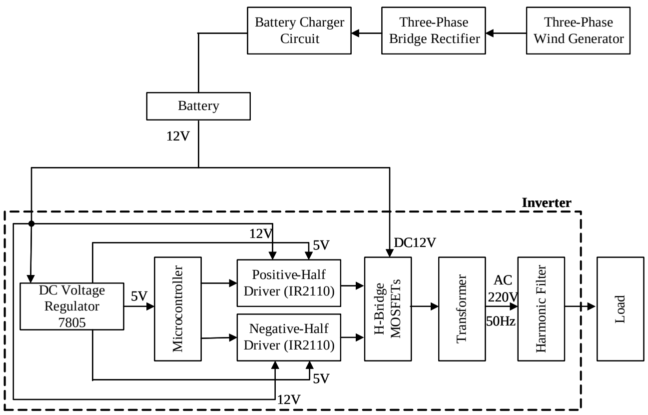


***Fig. 9.*** *Block diagram of inverter*

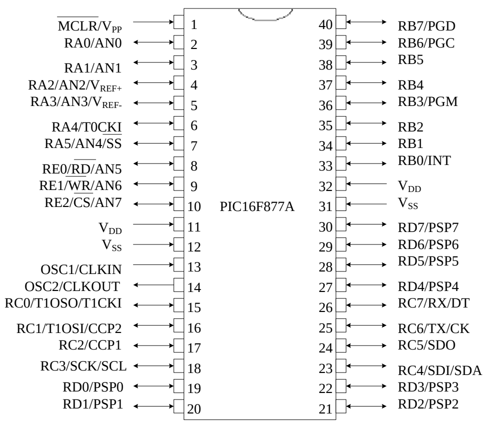


***Fig. 10.*** *Pin diagram of PIC16F877A [7]*

Switch mood power supply circuit converts DC source voltage into required voltage level for the microcontroller and MOSFETs driver circuit. The supply voltage for PIC microcontroller is 5V DC and 15V DC for MOSFETs driver circuit. In the circuit, 7805 and 7815 voltage regulator ICs are used. PIC16F877A microcontroller is used to generate the timing pulse for MOSFETs driver circuit. Pin diagram of PIC16F877A microcontroller is shown in fig. 10. In the circuit, RB7, RB6, RB5, RB4 pins are used as output pins for inverter and 4 MHz crystal is used for external clock. MOSFTs driver circuit prevents the overlapping of timing pulse for power MOSFETs. The most commonly used for MOSFETs and IGBTs is IR2110 IC. The IR2110 are high voltage, high speed power MOSFET and IGBT drivers with independent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 500 or 600 V.

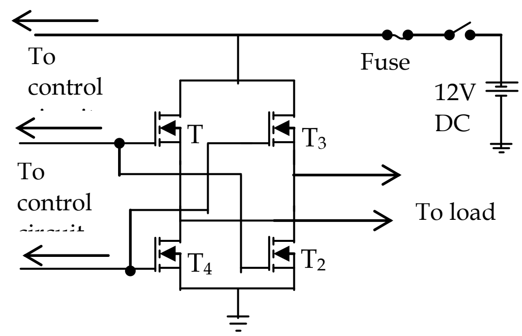


***Fig. 11.*** *MOSFETs H-bridge configuration*

The MOSFETs H-bridge configuration for inverter is shown in fig. 11. For positive half cycle pulses, transistors $T_3$ and $T_4$ operate and $T_1$ and $T_2$ operate for negative half cycle pulses. Transformer is used to step up the output voltage of inverter up to 220V. Harmonic filter is constructed with resonance arm inductor (L) and capacitor(C) circuit. The value of L and C mainly depends on switching frequency of inverter.

## 4 Simulation and Testing Results

Circuit simulation is done by Proteus software. The circuit diagram for simulation is shown in fig. 12.The simulation SPWM pulses output from microcontroller is shown in fig. 13. Test circuit assembly for microcontroller is shown in fig. 14. The SPWM pulses from microcontroller that measured in oscilloscope are shown in fig. 15. The simulation output of inverter is shown in fig. 16.

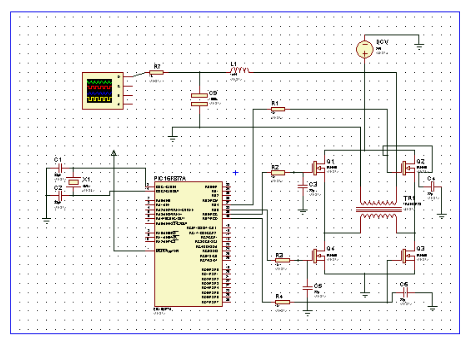

***Fig.12.*** *Circuit diagram for simulation*


***Fig. 13.*** *Simulation output of microcontroller*

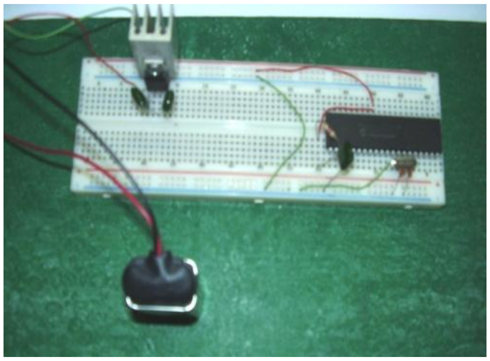

***Fig. 14.*** *Test circuit assembly for microcontroller*

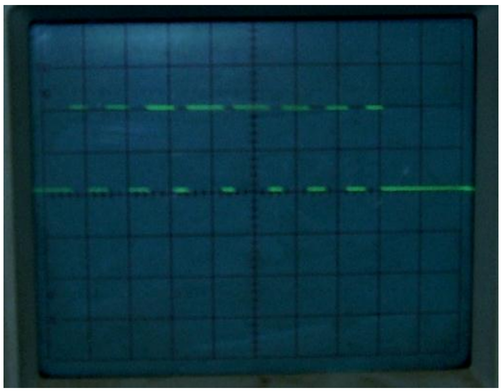

***Fig. 15.*** *SPWM pulses seen in oscilloscope*

***Fig. 16.*** *Simulation output of inverter*

## 5 Conclusion

In simulation circuit, MOSFETs are directly driven by the switching pulses of microcontroller. But, the driver circuits are necessary for practical construction. The output waveform of SPWM inverter is nearly sine wave. The more the number of pulses per half cycle are used, the smoother the output waveform. But, switching losses are also high for high frequency switching. Moreover, inverter grade high speed power MOSFETs or IGBTs are used for the inverter circuit. The further extensions are to implement condition that the internal voltage control system can be used in the inverter. For closed loop system, voltage and current sensing and analogue to digital (A/D) conversion processes are used in the microcontroller. To obtain the higher power rating, the power MOSFETs can be replaced by SCRs. But the driver circuit of the inverter must be changed. For grid connected wind electric system, the inverter frequency must be synchronized with the grid frequency and synchronizer circuit must be added in the inverter.

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