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Microcontroller Based Multilevel Inverter for Photovoltaic System

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This paper proposes the hardware design and implementation of a microcontroller based single-phase five-level cascaded H-bridge multilevel inverter for photovoltaic system. The inverter is capable of producing five levels of output-voltage levels ($2V_{dc}$, V_{dc}, 0, $-V_{dc}$, and $-2V_{dc}$) from the dc supply voltage. Selective harmonic elimination pulse width modulation (SHEPWM) technique was employed to improve the output waveform quality. Digital optimized switching angles algorithm was implemented in a low cost processor ATMega 8535 to generate switching signal. The proposed system was verified through a small-scale laboratory prototype was built and tested. Its results indicated the proposed method's effectiveness and the application feasibility of the fundamental frequency switching.

Keywords: Multilevel inverter; microcontroller; photovoltaic; SHEPWM.

1. INTRODUCTION

In the last years, people are more and more worried with the fossil fuel exhaustion. Fossil fuels have a huge negative impact on the environment and constant increase of costs of them. Renewable energy sources have proposed and developed due to the dependency. They are solar energy, wind power, biomass, geothermal and fuel cell. Among the various renewable energy sources, solar energy has been regarded one of the more important owing to its advantages: cost-free, abundant availability, and zero carbon dioxide emission. Thus, optimizing the usage of solar energy can sustain the environment and the balance of nature.

Solar radiations can be converted into either thermal energy or electrical energy or both [1]. Photovoltaic (PV) is the most useful way of employing solar energy by directly converting it into electricity via an electronic process that occurs naturally in certain types of material, called semiconductors. Application of PV systems has been widely applied in daily live such as calculator, car etc.

Generated electricity by PV module is DC source. An inverter need to convert PV's DC power to AC because most electric loads are AC.

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There are many types of inverters. Multilevel inverters that one of them have been attracting attention for their high-voltage operation capability, high efficiency and low electromagnetic interference (EMI). Multilevel inverters produce a desired output voltage from several levels of DC voltages as inputs. By taking sufficient number of DC sources, a nearly sinusoidal voltage waveform can be achieved.

Various topologies for multilevel inverters have been proposed; the most popular being the diode-clamped [3], [4], flying capacitor [5], and cascade H-bridge [6] structures. Among the three topologies, the cascaded H-bridge (CHB) inverter topology has the potential to be the most reliable and achieve the best fault tolerance owing to its modularity, a feature that enables the inverter to remain working at lower power levels after cell failure. Modularity also permits the cascaded multilevel inverter to be arranged easily for high power and high-voltage applications. Moreover, the switching stress for each power switching would be less than the regular two level topology, since the switch and diode need only withstand one separate DC voltage.

Multilevel inverter's efficiency parameter such as switching losses and harmonic reduction, depend on its

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modulation strategies mainly. There are two PWM techniques mainly used in multilevel inverter control strategy. One is high switching frequency and another one is low switching frequency techniques, often equal to fundamental switching frequency [7]. For high switching frequency classified as space vector PWM, and SPWM. While for fundamental switching frequency classified as, optimized harmonic stepped waveform [8], Selective harmonic elimination pulse width modulation (SHEPWM) [9], and optimal minimization of the total harmonic distortion (THD) [10].

Since multilevel inverters are frequently operated with low switching frequency, SHEPWM offers several advantages over the other methods. It can decrease the switching losses, eliminate some specific harmonic components. Finally, as mentioned above, the output voltage waveform is nearly is nearly sinusoidal which decrease the cost of the filter [11-15].

As digital power electronics are continually improving, Digital Signal Processor (DSP), and Field-Programmable Gate Array (FPGA) widely used. They were employed to control process and generate switching signals. They have a high speed processor, but the price is relatively expensive. The microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes.

Microcontroller based systems offer major advancement as an internal and external control. They can control majority of the internal devices in a typical circuit board. Moreover majority of the chips also have built-in interfaces that can be controlled by the microcontroller.

This paper addresses some theoretical and implementation issues of CHB multilevel inverter for PV system application. The switching angles for power switching are optimized via SHEPWM technique. The optimized switching angles are implanted in a low cost processor ATMega 8535.

2. PHOTOVOLTAIC INVERTER CONFIGURATION

The PV generation system structure is shown in Fig.1. The system comprises PV array, charge controller, battery, the inverter, and AC load. The charge controller was employed to extract maximum power from PV array. The maximum power point tracking (MPPT) algorithm is implanted in the charge controller. Energy of PV array is injected to battery. The inverter used in this configuration is a CHB multilevel inverter, whose can generate five-level of DC voltages. The switching angles of this inverter is optimized via SHEPWM technique. Newton-Raphson method can be used to solve the non-linear equations of SHEPWM technique [16-19].

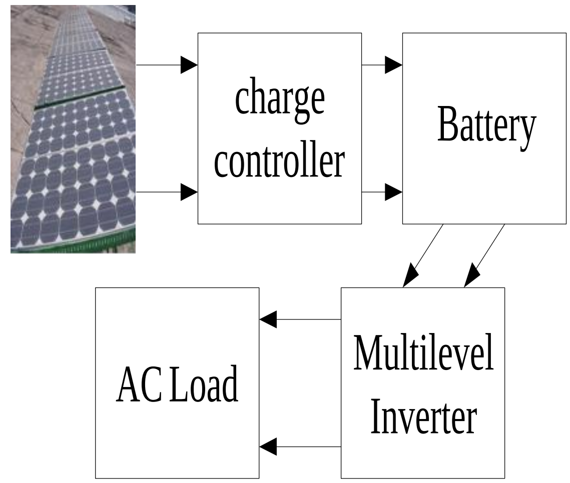

Fig. 1. Photovoltaic inverter configuration

3. CHB MULTILEVEL INVERTER

A full-bridge inverter is known as an H-bridge cell. The inverter circuit consists of four main switches and four freewheeling diodes. The power circuit of a five-level CHB multilevel inverter is shown in Fig. 2. CHB multilevel inverter is based on series connection of single phase H-bridge inverters with their own isolated DC sources, which may be obtained from solar cells, fuel cells, batteries, ultra-capacitors, etc. The modular structure of CHB multilevel inverter leads less space occupancy than other topologies. This topology requires less number of components compared to the flying capacitor and diode clamped multilevel inverter topologies. In addition to the above, this type of converter does not require a specially designed transformer as like in the multiphase inverters or clamping diodes or flying capacitors [20]. Considering the simplicity of the circuit and advantages, CHB multilevel inverter topology is chosen for the presented work.

The output voltage of cascaded multilevel inverter (see Fig. 3) is equal to the summation of the output voltages of the respective modules that

$$V_o = V_{m1} + V_{m2} \quad (1)$$

Where

V_0 = output voltage inverter

V_{m1}= output voltage of module 1

V_{m2}= output voltage of module 2

Each module of this inverter has its own DC source (V_{dc}) and consists of four power devices designated as $S1_i$, $S2_i$, $S3_i$ and $S4_i$. The symbol i is number of module.

The states of operation switching for this inverter to generate five output voltage levels ($+2V_{dc}$, $+V_{dc}$, 0, $-V_{dc}$, and $-2V_{dc}$) are shown in Table 1.

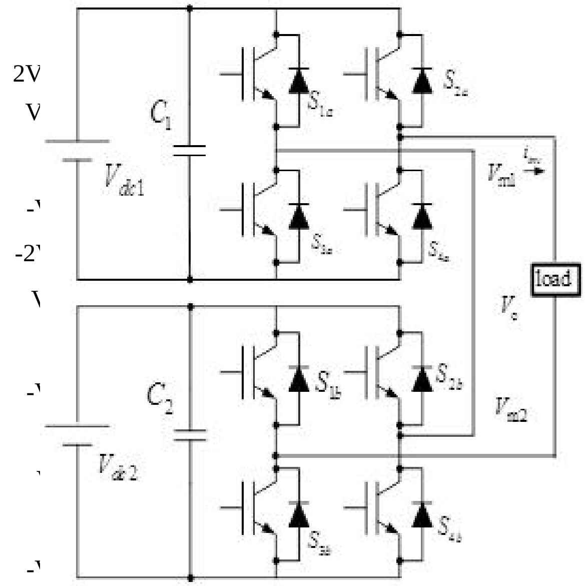

Fig. 2. The single-phase CHB multilevel inverter

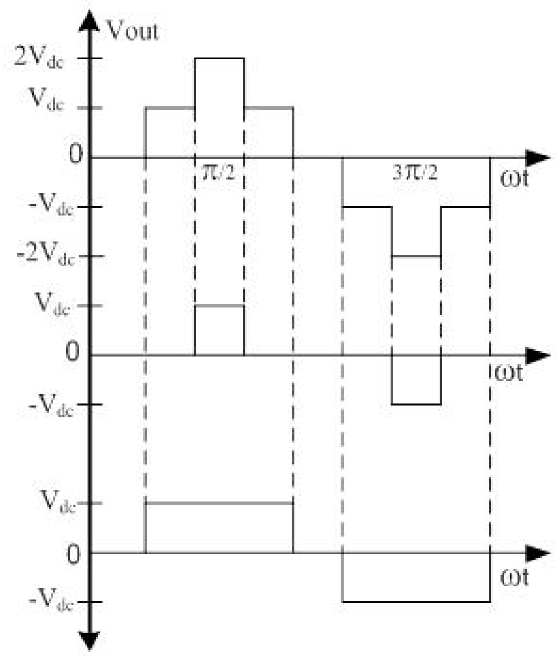

Fig 3. Output Voltage of CHB five level inverter

Table I. Output voltage according to the switches on-off condition,

Power devices index								Output voltage		
S_{1a}	S_{2a}	S_{3a}	S_{4a}	S_{1b}	S_{2b}	S_{3b}	S_{4b}	V_{m1}	V_{m2}	V_o
1	0	0	1	1	0	0	1	$+V_{dc}$	$+V_{dc}$	$2V_{dc}$
0	0	0	1	1	1	0	0	$+V_{dc}$	0	$+V_{dc}$
1	1	0	0	1	1	0	0	0	0	0
0	1	1	0	0	0	1	0	$-V_{dc}$	0	$-V_{dc}$
0	1	1	0	0	0	1	0	$-V_{dc}$	$-V_{dc}$	$-2V_{dc}$

1 = on and 0 = off

4. MICROCONTROLLER ATMEGA 8535

The ATmega8535 was used to store the switching angles in this research. The ATmega8535 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing instructions in a single clock cycle, the ATmega8535 achieves throughputs approaching 1 MIPS per MHz allowing the system designed to optimize power consumption versus processing speed.

All pins (Port A.0 – Port A.7) of port A in ATMega 8535 is employed to generate switching signals. The gating signals were generated by the ATmega8535 I/O port by assigning logic “0” or “1” for the corresponding I/O pin-out. Port A.0 – port A.4 are used for $S1_a$ –$S4_a$, and Port A.4 – port A.7 are used for $S1_b$-$S4_b$. The oscillator clock is set 1MHz, and supply voltage of VDD = 5 V.

5. EXPERIMENT RESULTS

In this experiment, several apparatus have been used to measure the CHB multilevel inverter output performances. This experiment is to observe the capability on generate the gating signals using the microcontroller. A power analyzer (Fluke® 434/PWR) is used to record the harmonic content of the voltage waveform. A 4-channel digital oscilloscope (GwINSTEK GDS-2074A) is used to capture the gating pulses as well as the CHB multilevel inverter output voltage waveforms.

To verify the validity of the proposed inverter, a prototype was designed and built. Ten SIEMENs SP75 modules were connected in series and parallels to produce 750 W peak of power. The optimized switching angles were determined with Newton-Raphson method. The lowest THD of the switching angles were chosen to implant to microcontroller target board, with modulation index, m_a=0.84, ¯$_1$=17.06^0, ¯$_2$ =43.53^0

In Fig. 4 and 5, ATMega8535 target board was employed to generate the switching signal that fed to CHB multilevel inverter. Fig. 6 shows the experiment result for the output voltage waveform, whose harmonic content (THD = 15.9%) is shown in Fig. 7.

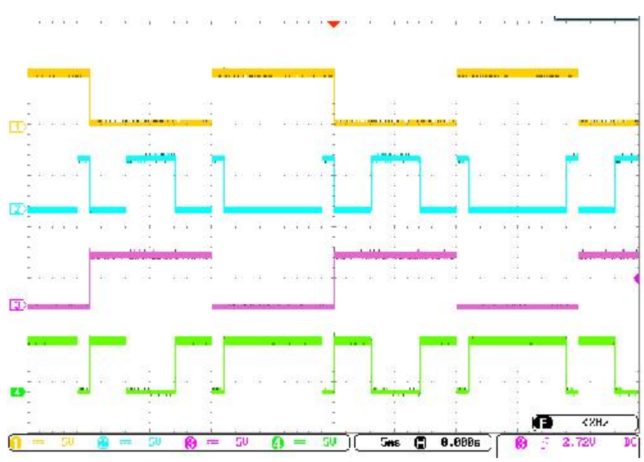

Fig. 4: Switching angles S_{1a}-S_{4a} for m_a=0.84, ¯$_1$=17.06^0,

¯$_2$ =43.53^0

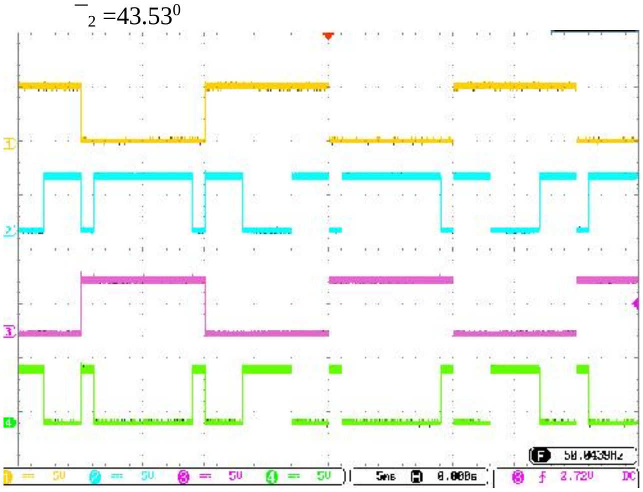

Fig.5: Switching angles S_{1b}-S_{4b} for m_a=0.84, ¯$_1$=17.06^0, ¯$_2$ =43.53^0

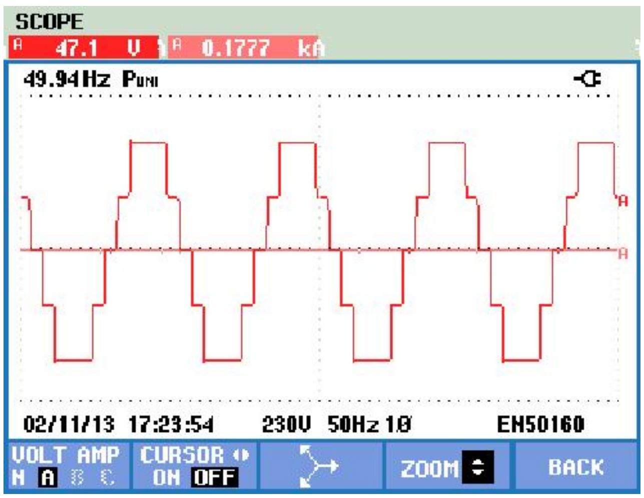

Fig. 6: Output voltage m_a=0.84, ¯$_1$=17.06^0, ¯$_2$ =43.53^0

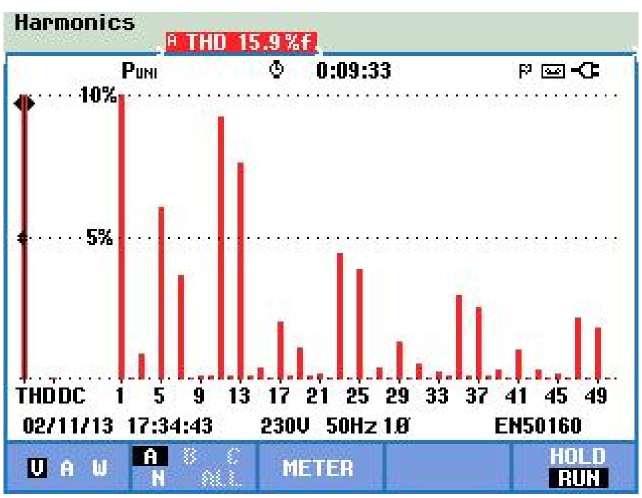

Fig. 7: Harmonic content output voltage waveform for m_a=0.84, ¯$_1$=17.06^0, ¯$_2$ =43.53^0

Meanwhile, for the switching angles that have not optimized, such as ¯$_1$= 30^0, ¯$_2$ = 75^0, the output voltage waveform was shown in Fig. 8 and spectrum current harmonic for this switching angles was shown in Fig. 9.

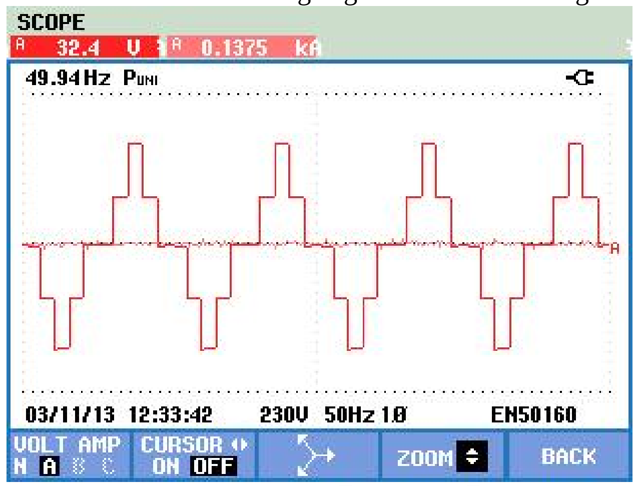

Fig. 8: Output voltage ¯$_1$= 30^0, and ¯$_2$ = 75^0

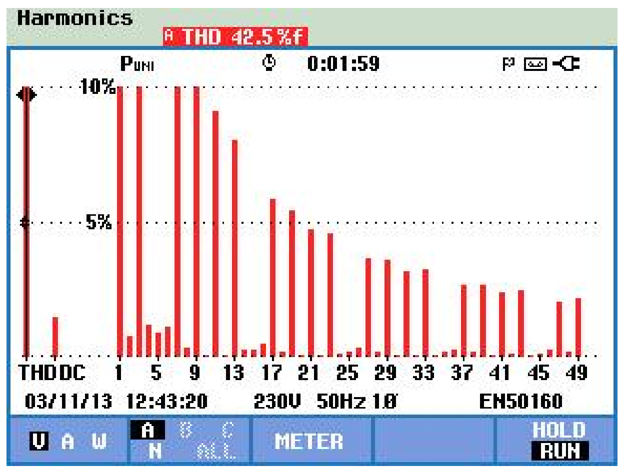

Fig. 9: Harmonic content output current waveform ¯$_1$= 30^0, ¯$_2$ = 75^0,

Hardware setup for this CHB multilevel inverter with ATMega8535 based is shown in Fig.10.

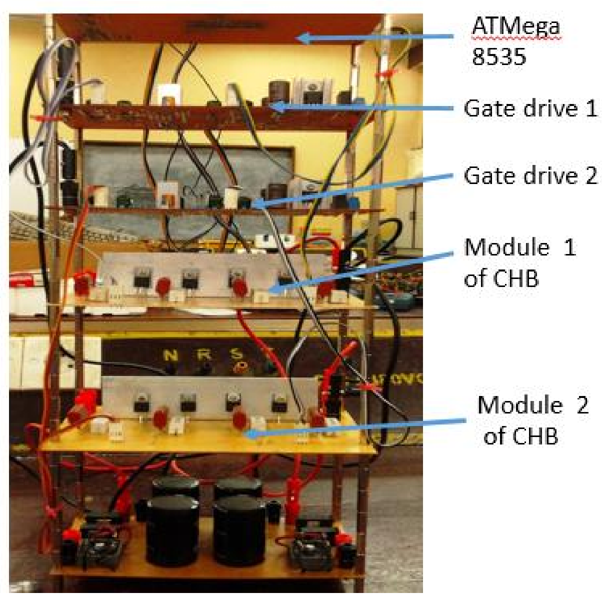

Fig. 10: Hardware setup

5. CONCLUSIONS

A microcontroller based CHB five-level inverter scheme for use in a stand-alone PV power generation system has been proposed. Low switching frequency algorithm was implanted in the microcontroller target board. This low cost processor has been successfully applied for CHB five level inverter. The optimized and non-optimized switching angles have been engaged with ATmega8535 and verified by experiment results.

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