Design and Simulation of Programmable AC-DC Converter using Pulse Width Modulation (PWM) Techniques in MATLAB

Gailan Abdul Qadir, Majid S. Naghmash

Abstract— This paper presents, a design of Programmable AC-DC Converter Using Pulse Width Modulation (PWM) Techniques in MATLAB with an impression of the well known voltage and current converter topologies used to realize a three-phase PWM AC/DC converter scheme. Preliminary from the voltage source inverter and the current source rectifier, the fundamentals of space vector modulation are summarized. The process of the AC/DC converter in different dynamic states powerfully depends on the modulation method applied. The power of the discussed modulation methods on the line current distortion and the switching frequency has been inspected. This technique depends on off line calculations of the pulses width for the first quarter cycle and stores these into a table. The residual pulses, for total cycle, are generated by using the values of the first quarter since there are conditions of quarter and half – wave regularity. Results show an important saving of microcontroller time and memory.

Keywords AC/DC, MATLAB.

I. INTRODUCTION

The method of Pulse Width Modulation (PWM) has establish broad acceptance for controlling electronic switching power inverters. PWM control signals were initially generated with the assist of electronic hardware, although recently microcontrollers have begin to play an vital role in the design and control of signal generators for power inverters, regularly assuming additional functions[1]. In previous systems, a microcomputer was used to generate the orientation signal, whilst the timing signal and the actual PWM signals were produced by electronic hardware [1,2]. Afterward, systems were improved with a microcomputer, used to compute switching points for PWM patterns with preferred harmonic removal and to recover recomputed patterns from look-up tables. In a velocity control systems, with a large range of generated frequencies a microprocessor was used to generate PWM or a six-step unmodulated signal and to maintain a constant voltage/ frequency ratio. Because of computation speed limitations found in many of the available microcomputers previously, it was concluded that the on-line computation of switching patterns was not practical. However the latest advances in microelectronics produced new microcomputers with faster speeds so that the switching pattern can be computed on line.

The dynamic development of the power- and microelectronics devices sustains continual progress in design and realization of modern adjustable speed drives. The attention of researchers in the amplification of superior control techniques for voltage source inverters was in previous two decades stimulated by AC/DC line-side converters called also PWM rectifiers. These front-end rectifiers due to their properties systematically displace the diode bridges becoming an important part of the modern frequency converters for the intelligent motion control applications [2,3]. The three-phase two-level AC/DC line-side converters provide sinusoidal line currents and bidirectional power flow at the unity power factor (UPF). These properties have decided of the use of the PWM rectifiers in the applications improving the electrical power quality [4].

The major mission of the control scheme in a current control-PWM converter is to force the currents in a three-phase AC load to follow the reference signals. By comparing the command and measured immediate values of the phase currents, the current control generates the switching states for the converter power devices which reduce the current errors. Therefore, in general, the current control implements two tasks, the error compensation and modulation [5].

The AC/DC converters consist of power electronics devices like Insulated Gate Bipolar Transistors (IGBT) or Gate Turn-Off thyristors (GTO) that are characterized by switch mode operation. The capability of forming sinusoidal currents is provided by the introduction of the sophisticated technique called Pulse-Width Modulation (PWM). This technique provides the sequences of width-modulated pulses to control power switches. Many PWM techniques have been developed according to special requirements and optimization criteria. The choice of the particular PWM technique arises from the de-sired performance of the synchronous rectifiers [6,7]. Generally pulse-width modulation techniques for frequency converters may be classified as follows: Carrier-Based Sinusoidal PWM, Hysteresis-Band PWM, Space Vector PWM, Selected Harmonic Elimination PWM, Minimum Current Ripple PWM, Sinusoidal PWM with Instantaneous Current Control and Random PWM. This paper presents basic assumptions and applications of selected, most frequently used modulation techniques applied to PWM rectifiers. For the comparative analysis Voltage Oriented Control of the AC/DC line-side converter has been chosen to examine the proposed modulation methods. The topology of the voltage source AC/DC converter connected to the grid is presented in Fig.1[8,9]. The power circuit of the synchronous rectifier stems from the topology of the three-phase PWM voltage inverter. The

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PWM rectifier's bridge consists of six fully-controlled IGBT transistors connected to the supply line throughout the three symmetrical line inductors. The voltage drop over line chokes has to be controlled to provide sinusoidal line currents. In this research three phase PWM control signals are generated and the output voltage is controlled.

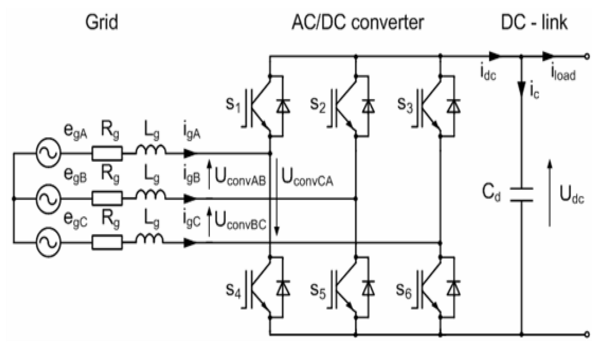

Figure.1. Voltage source AC/DC line-side converter

II. MODULATION TECHNIQUES

The modulation technique used in a PWM signal generator should satisfy a number of requirements including, the frequency of the fundamental generated signal component should be varied within a wide range, the amplitude of the fundamental component should be controllable with high resolution and the generated signal should have a low overall harmonic content. A modulation technique, which satisfies these requirements, was selected for implementation. It is a modification of the popular triangular modulation technique. The PWM signal in each phase of the output is formed when a reference signal, a sine wave of a desired frequency, is compared with a timing signal, a triangular wave of higher frequency. In order to improve the harmonic contents of the resultant PWM signal, the reference and timing waves have to be synchronized, i.e for any desired frequency of output signal, there must be an integral number of timing wave periods per each period of the reference wave. A more detailed analysis indicates that the frequencies of the reference and timing wave should satisfy the following relation: [10,11]

$$f = 6.n.F \qquad (1)$$

where :

f: timing wave frequency

F: reference wave frequency

$n \geq 1$. an integer.

When the conventional triangular modulation is used, the PWM signal, which results from the comparison of the reference and timing wave, is a bipolar signal, which changes polarity many times during a half-period of the reference wave. Used as a control signal for switching inverters, it may cause dangerous short circuit conditions ("shoot-through") in an inverter at each moment when the PWM signal changes polarity. To avoid this danger, a special "lock-out" time interval is usually inserted into the PWM control signal at each of its zero crossing.

The danger of shoot-through conditions is eliminated if the polarity of the timing wave is made the same as the polarity of the reference wave as shown in Fig (1). The resulting PWM control signal would toggle only one (upper or lower) transistor in each phase of the inverter during a whole half-period of the reference signal for a given phase, while the other transistor would remain OFF. The modulation technique with the above properties has been named unipolar modulation[12,13].

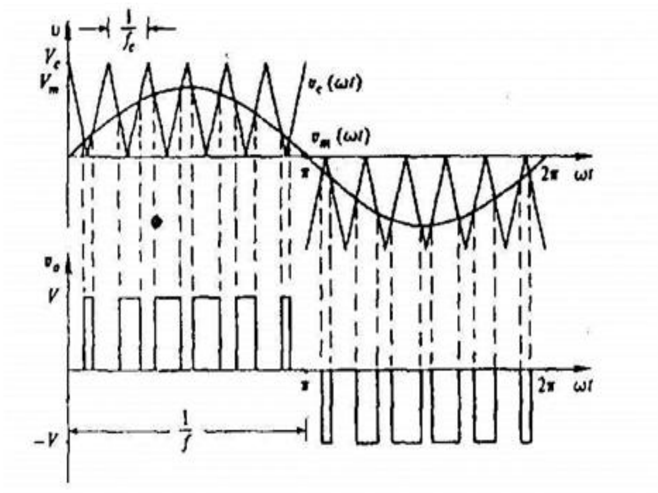

Fig (1) Reference and timing wave forms for unipolar pulse width modulated control signal

Interest has been growing in microcomputer-based pulse width modulator (PWM) schemes for A.C drive systems in recent years. A microcomputer-based modulator, if judiciously designed, can provide considerable simplification of hardware with significant improvement in performance. The hardware simplification also adds to the reliability improvement. Modern PWM A.C drive systems are continually seeking improvement of performance and reliability with reduction of control and power conversion cost. If the drive control system is implemented with a microcomputer, then the modulator, which constitutes a compatible link between the controller and the inverter, can be integrated into the hardware and software of the same microcomputer. If the modulator is used in the discrete form as a block box, a possibility exists that a universal hardware module can be designed which can be adapted to transistor or a thyristor drive of different specifications simply by modifying the software. [14]. The performance improvement by a microcomputer-based modulator can be briefly reviewed here. In a conventional hardware modulator, the PWM waveforms are generated by comparing the sine reference wave with triangular carrier wave by the "natural sampling" process. As the linear PWM region is exceeded into the transition region, the harmonic quality of the waves deteriorates seriously with the introduction of the lower order harmonic. In a microcomputer-based modulator, the wave can be synthesized precisely in the transition region controlling the harmonics and voltage jump, and the non-linearity problem can be easily overcome.

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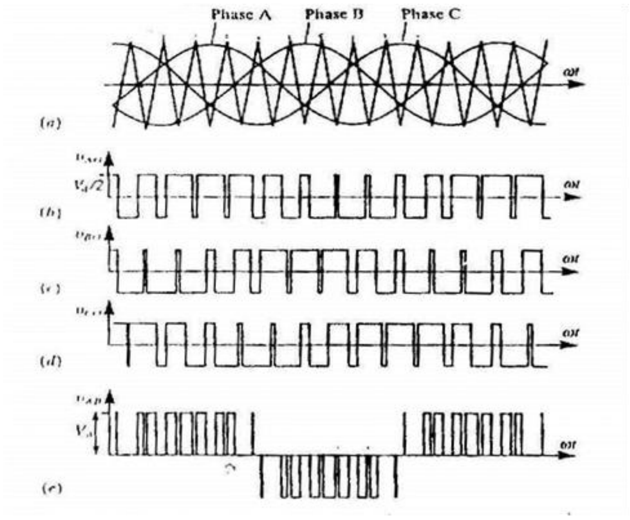

Fig(2). Three phase sinusoidal PWM the reference voltage and line voltage

III. DIGITAL PWM TECHNIQUES

One of the goals of the replacement of the conventional analog and digital devices with the LSI (large-scale integration) packages, such as microprocessors and microcontrollers in the controllers of PWM inverters is to make possible the implementation of the digital modulation technique. Two methods have been used for implementing the digital modulation techniques on a microcontroller. In the first one computes off line the switching angles for some levels of the first harmonics of the inverter output voltage and stores them in the micro controller memory as a look-up table [7,8]. This saves the microcontroller the task of obtaining the angles, allowing it to operate in real time. The second method, one demands of the microcontroller the on-line computation of the switching angles. This will need high-speed microcontroller to operate in real time for accommodating the numerical algorithms required to obtain angles. In typical ac motor-controller design, both hardware and software considerations are involved in the process of generating the PWM signals that are ultimately used to turn on or off the power devices in the three-phase inverter. In typical digital control environments, the microcontroller generates a regularly timed interrupt at the PWM switching frequency (nominally 10-20 kHz). In the interrupt service routine, the software computes new duty-cycle values for the PWM signals used to drive each of the three legs of the inverter. Typical PWM signals produced by the microcontroller are shown in Fig. (3)[9,10].

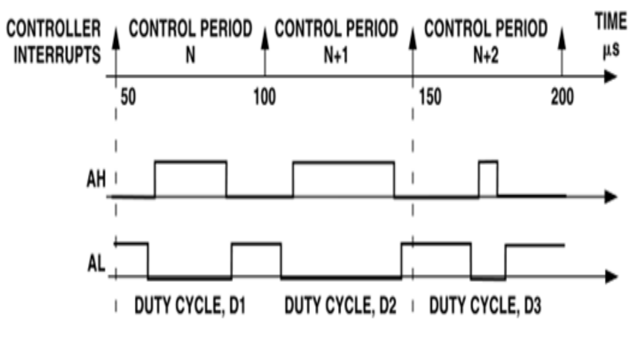

Fig (3) Typical PWM waveforms for a single inverter leg.

IV. PROPOSED FEEDBACK VOLTAGE CONTROL

The proposed approach to control the output voltage (voltage regulation) is by off line computing the firing angles (α) for the expected voltage variation in this application (36v, 34v, 32v), using selective harmonic elimination pulse width modulation (SHE PWM) technique. Then these (αs) are stored in the 3-location of the memory. The control unit will choose the suitable location for each variation of the voltage to maintain the output voltage at the required value.

V. PROPOSED FEEDBACK VOLTAGE CONTROL

The model shown in figure (4) shows the proposed method in MATLAB. Since during the voltage variation on the output the on- line computation of the firing angle causes the output signal to be unstable because of the limitation of the speed of the microcontroller, that is not sufficient to compute all pulses as shown practically. Hence three tables of firing angles is computed off line by the method mentioned in the above example, then stored in microcontroller. The model specifications could be described in Table 1.

Table 1: proposed model specifications

Descriptions	**Values**
Converter rating	500 Volts DC, 500 kW
AC Supply: three-phase	600 V, 30 MVA, 60 Hz system
Voltage-sourced Converter (VSC)	Three-level, three-phase
Link: 2 capacitors	75000 uF
Two sample times	Ts Power = 5 us , Ts Control = 100 us

The primary conditions are set at the begin of the simulation. This file has been generated by running an initial simulation to steady-state for an integer number of cycles of 60 Hz. One can see that the dynamic response of the DC regulator to this sudden load variation is acceptable. The DC voltage is back to 500 V within 1.5 cycle and the unity power factor on the AC side is maintained. At t=100 ms, a "Stop Pulsing" signal is activated. However, the DC voltage drops to 315 V. A radical change in the primary current waveform can also be experiential. When the pulses are blocked, the Three-Level Bridge block operation become similar to a three-phase diode bridge.

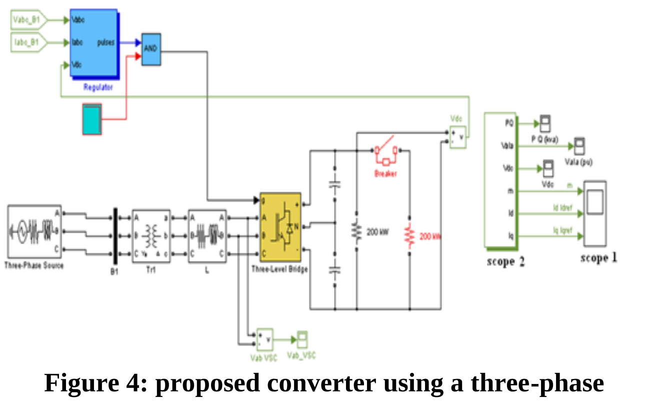

Figure 4: proposed converter using a three-phase three-level PWM Voltage-sourced Converter

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The following signals could be observed during the simulation as show in Figure 5 and Figure 6.

- The DC voltage (Vdc)
- The primary voltage and current (phase A)
- The AC supply (VaIa)
- The device currents of leg A of the IGBT bridge
- The phase-to-phase AC voltage generated by the VSC (Vab)

When t=50 ms, a 200-kW load is switched-in. However, the active response of the DC regulator to this unexpected load deviation (200 kW to 400 kW) is acceptable. The DC voltage is back to 500 V within 1.5 cycle and the unity power factor on the AC side is maintained.

When t=100 ms, a "Stop Pulsing" signal is activated (pulses normally sent to the converter are blocked). Hence, the DC voltage drops to 315 V. An extreme alteration in the primary current waveform can also be practical. When the pulses are blocked, the Three-Level Bridge block operation becomes similar to a three-phase diode bridge.

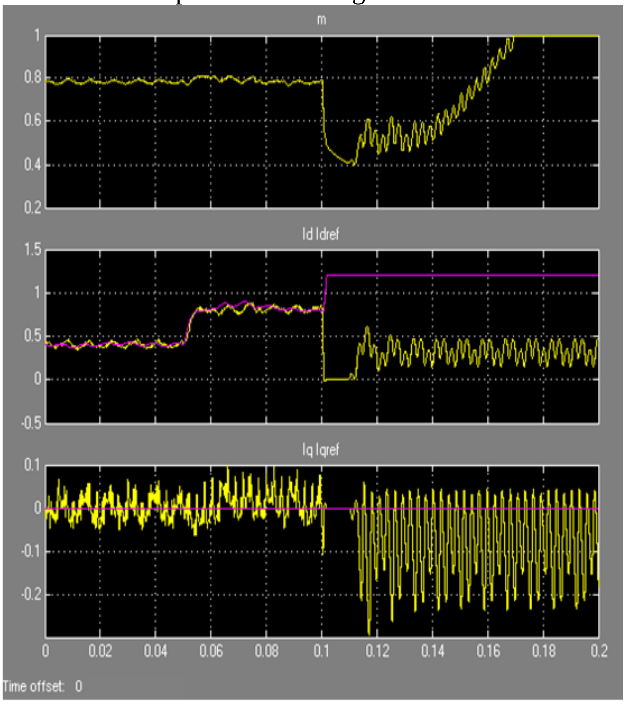

Figure 5: simulation results scope 1

The preliminary conditions necessary to start in steady state have been saved in the Table. After one change this model, or change parameter values of power mechanism, the initial conditions stored in the Table variable will no longer be valid and Simulink will issue an error message.

A new method is used to generate the PWM signal which controls the firing of the power circuit, where the period of PWM pulses are calculated by solving the set of equations off line to obtain the suitable firing angles represent the required output voltage. Another set of firing angles is calculated for the expected voltage variation due to loading. These angles are stored in the microcontroller memory. If the voltage varies the microcontroller senses the voltage variation by taking all measurements, hence changing the duty cycle (PWM) signal in a way that suits the new voltage value in order to maintain the required voltage constant during load variation. This checking process on the output voltage occurs every 1 msec by the microcontroller.

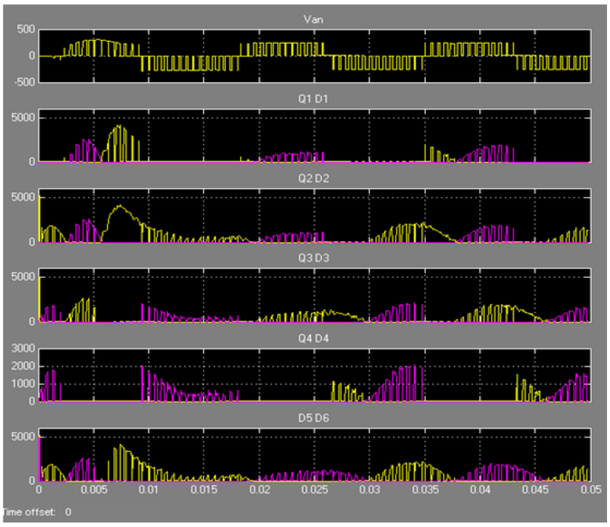

Figure 6: simulation results scope 2

VI. CONCLUSION

The inclusive analysis of the preferred pulse-width modulation techniques in the purpose of AC/DC line-side converters is presented in this paper. The PWM technique offer brilliant dynamics during the direct line currents tracking. The PWM technique permits the switching pattern to be appreciate on-line. This method regardless of the ease completion is tainted by the unreliable switching frequency accounting for the high current ripple. The mechanism of the Sinusoidal PWM method might decrease the upper harmonics satisfied in the line currents because the carrier signal inflict around constant switching frequency of the power transistors. Dissimilar current organize carrier-based modulation straight impose sufficient converter input PWM voltages to track their reference standards. Therefore, the major difficulty is the efficiency of the DC-link voltage conversion into the PWM system at the input of the AC/DC converter. The purposeful distortion of voltage reference signals by the third harmonics is the majority effective method to expand the linear range of the carrier-based modulation. A wide range of the linearity and the enhanced harmonic presentation even though the high computational effort and the complexity of the implementation could be provides by using PWM method. PWM voltage could be then formed through an open-loop control system. Therefore, the control system of the synchronous rectifier does not show the high dynamic presentation and the effects of instability are not mechanically compact.

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