Simulation based Design for Inverter Power Supply

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Abstract: Inverter power supplies have been developed as an analog circuit. Over the past decade, digital control has emerged as a viable candidate for the inverter power supplies due to the benefits which can be added by applying the digital control. However the complexity of digital control has been dramatically increasing.   One of the leading methods in the digital control design is the model based development technique.   Modeling and simulation act as the first step of model based development technique and they are very useful for the development and implementation in both hardware and software design.   They can lead to improve the performance, reduce development and production cost and time.   This paper constructs a Model In the Loop Simulation (MILS) environment for designing the embedded software for the inverter power supply. The principle of the operation and the key features of using the digital PWM controllers are presented. Important software parameters are optimized using the simulator.   To verify the validity of the developed model, comparisons between the circuit simulation and experimental results are shown.   The illustrations show that the results obtained by the developed model are in good agreement with the experimental results.

Keywords: DC/AC power conversion, pulse width modulation, microcontroller, embedded system

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1. Introduction

Inverter power supplies are widely used in many industrial processes and applications, such as, uninterruptable power supplies, motor control, and electric vehicle applications. An inverter power supply can be defined as a device that converts DC (Direct Current) from sources such as batteries, solar panels, fuel cells, or wind generations to AC (Alternative Current) so that the output can be used in a wide range of AC applications. Traditionally, an analog control technique is used to control the inverter power supply. However, due to the fact that a digital control technique can provide the benefits which can not be provided by an analog one, a digital control starts to be used. Actually, a digital controller can offer a programmable solution for the applications. Moreover, it also offers the flexibility in design and an advanced algorithm and additional features can be added to the controlling software instead of hardware. From the electrical view point, a digital controller is less sensitive to the environmental conditions and shows precise behaviors compared to analog counterparts [2, 3, 11, 13].   However, the complexity of digital control in many applications has been dramatically increasing over the past few years It is becoming difficult to monitor the control behavior for the actual design. In the digital control the system consists of two parts the first part is the control parts which include the microcontroller or DSP and the control software (embedded software), the second part is the controlled system which could be electrical or mechanical part. Most of previous work concentrated in the second part simulation. Traditionally, the software part is tested in the actual prototypes which can leads of system failure as well as it takes so much time and cost to obtain the optimum system behavior.   Therefore, most of research attention is concentrated to solve the above problems. One of the leading solutions of this problem is to apply model based development technique. In this method the model can be used to verify the plant design and the control algorithm. This method has many advantages, that is, it can provide insight into the system performance and allow for analysis of the design before it is implemented in the hardware and software, which can lead to improve the performance and reduce the time

and cost [1, 5,7]. This paper describes how the model based design can offer an effective solution by constructing Model In the Loop Simulation (MILS) environment for designing the embedded software.

This paper is organized as follows. Section 2 includes the description of the inverter power supply topology. A single phase pulse width modulation is presented in Section 3. Section 4 presents the description of the MATLAB model of the inverter power supply and comparisons between the simulation and the experimental results are described in Section 5.

2. Description of Inverter Power Supply

As aforementioned, an inverter power supply is a device which can convert DC to AC that can be used in various AC applications. It can be classified into two main groups, single stage inverters and multi stage inverters. Each group has different topologies, multi stage inverters will be described in this section. A multi stage inverter is defined as an inverter with more than one stage power conversion. T here are many different topologies which are used to determine the parts of the inverter power supply which are listed below [13]:

    1)   DC-DC-AC topology,

    2)   DC-AC-DC-AC topology, and

    3)   DC-AC-AC topology.

The choice of such topology depends on many factors, such as, size, cost, efficiency and capability. In this paper, DC-DC-AC topology will be used; its configuration is broken into two stages. The first stage is to step up the DC voltage level by using a DC/DC converter and the second stage is to convert DC to AC through a DC/AC inverter. Each stage can be controlled individually or synchronously. The block diagram of the inverter power supply is shown in Fig.1.
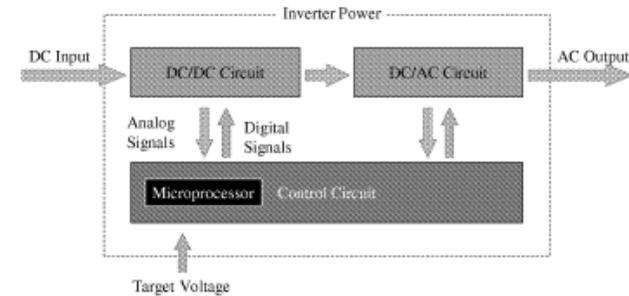

Fig.1 Block Diagram of Inverter Power Supply

2.1 DC/DC Converter

As shown in Fig.1, the first step of the inverter power supply is to step up the DC voltage level to the higher DC level by using a DC/DC converter. One of the simplest and most effective cost- configurations of DC/DC converter is the full bridge configuration shown in Fig.2. This type of converter operates by varying the pulse width at the switch gates of the transistors, which varies the average voltage at the mid point (V_A, V_B) of each leg by using the Pulse Width Modulation (PWM) technique. The output voltage taken across the midpoints is applied to the transformer which is responsible for boosting the voltage V_1 to the higher level voltage V_2.
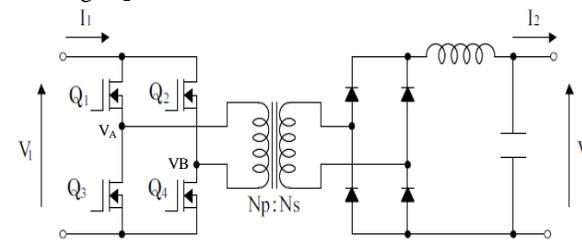

Fig.2 Circuit Schematic of DC/DC Converter

2.2 DC/AC Inverter

The second stage of the inverter power supply is to invert the new DC level into AC voltage through a DC/AC inverter. The most common topology is a full bridge configuration because of its easy filtering [4, 11]. A single phase full bridge inverter is shown in Fig.3. The PWM pulses which are generated by a microcontroller are fed into the gates of the full bridge inverter. Programming a microcontroller allows the transistors Q1 and Q4 to be on while Q2 and Q3 to be off and vice versa.
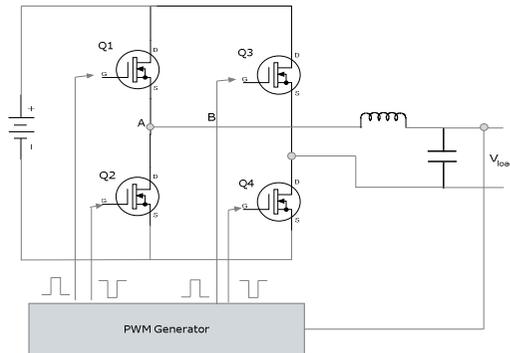
Fig.3 Circuit Schematic of DC/AC Inverter

Protection is implemented by providing a short time delay between the turning off of switching device to the turning on of the other switching device in the same leg to prevent shorting of the DC bus (current short thought) which is called "dead time" [3]. The shorter is the dead time, the better is the inverter performance. It is usually between 1-5 μs. The details about the PWM pulse generation and microcontroller programming will be mentioned in Section 3.

2.3 SH Microprocessor

In the inverter power supply applications, the microprocessor is used to control the switching period of the transistors as a digital controller. However, due to the fact that a digital PWM technique can provide the benefits which can not be provided by an analog one, a digital PWM technique starts to be used [5, 8]. The standard method for generating PWM pulses by using a microcontroller or DSP is by using one of the built-in PWM modules. These modules operate by comparing a free running timer with a duty cycle and duty period register. When a matching occurs between the timer and duty cycle register, the corresponding pin is either set to "high" or "low". The matching between the timer and the duty cycle register also causes the timer to reset to zero and then, to restart counting [3, 8]. Depending on the type of microcontroller or DSP, the PWM can be classified into "left-aligned", "center-aligned" or "right-aligned". To improve the performances of the digital PWM pulses, a digital control technique should be used. The digital PI (Proportional and Integral) controller is used to control the generation of PWM pulses. The main reason to use the PI controller is its simplicity and flexibility [8]. In this paper, a Renesas SH-2 microprocessor is used to control the generation of the PWM pulses which control the operation of both DC/DC and DC/AC circuits. The block diagram of the microprocessor is shown in Fig.4.
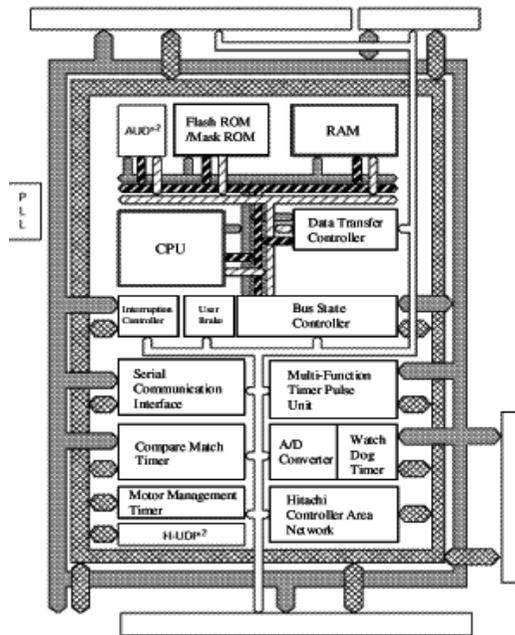
Fig. 4 Block Diagram SH Microprocessor

In the SH-2 Microcontroller, there are two separate control units in the SH microcontroller which are Motor Management Unit (MMT) which controls the generation of the PWM pulses in the DC/DC stage and Multi Function Timer Pulse Unit (MTU) which controls the generation of the PWM DC/AC stage[9]. Embedded software that is implemented in the microcontroller can be divided into three main tasks which are the wave generation program, the control algorithm program and the man machine interface program.

3. Pulse Width Modulation

Nowadays, Pulse Width Modulation (PWM) plays a major role in the generation of pure sine waves [11]. PWM can be defined as a switching method which is used for the inversion of DC to AC, where the pulse width (duty cycle) at the switching gates of the transistors varies according to a sinusoidal reference signal (control signal). Generation of PWM patterns can be done by using two different techniques which are analog or digital techniques [6, 12]. For understanding the methodology of PWM, an analog PWM is described below. The PWM can be done simply by comparing a sinusoidal control signal at the desired frequency with a triangular wave form (carrier signal). At each point, where the control signal and the carrier signal intersect, the output of PWM toggles from a high state to a low as shown in Fig.5.
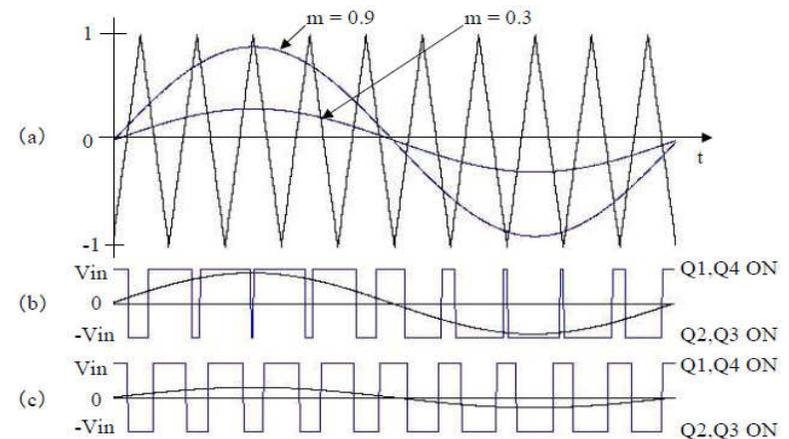

Fig.5 PWM Pulse Generation

The frequency of the carrier signal is generally kept constant along with its values. The control signal is used to control the switching duty by changing its values as a factor called modulation ratio "m" as described in equation (1).

$$m = V_{controller} / V_{carrier} \qquad (1)$$

where, $V_{controller}$ is the peak amplitude of reference sine wave and $V_{carrier}$ is the peak amplitude of saw-tooth wave, respectively. In this paper, digital PWM technique is used by utilizing SH microprocessor to control the generation of PWM pulses as described in Section 2.

4. Description of MATLAB and Simulink Model

Due to the complexity of the digital control design, the model based development technique is considered one of the leading solutions. In this method, modeling and simulation are considered as vital parts of design. Particularly, the simulation is indispensable for developing a controller programs. It can lead to the performance improvement and the reduction of the cost and the time for development and production. There is variety of software tools that are used for that purpose including MATLAB and Simulink. MATLAB and Simulink are software tools designed for modeling, simulating and analyzing the design of devices. It supports linear and nonlinear system models in continuous time, sampled time or combination of both It consists of a set of blocks such as communications, controllers, power systems and neural networks, etc. There are a lot of available tools that can be used in the MATALB environment to design and optimize the performances in an effective and easy way [10]. In our approach, the MILS (Models In the Loop Simulation) environment of the inverter power supply is constructed to optimize the parameters of the embedded software. MILS model is divided in two main parts which are the controlled part (electric DC/DC and DC/AC circuits) and the control part consisting of the microcontroller and the embedded software. As shown in Fig.6, a full simulator of the inverter power supply including electric circuit model and the functional model of the microprocessor is developed by using the MATLAB and Simulink environment. The electric part is developed using the Simulink power block set which consists of power electronic devices and elements such as inductance, capacitance and resistance. The control part is modeled by simulating the function of the microprocessor which is the embedded system function. The embedded system function can be divided into two main parts which are the control program (PI controller) and the PWM generation program.

4.1 Control Program

PI controller has been used in many industrial applications. The main purpose for using the PI controller is to control the PWM generation by controlling the modulation ratio m. The proportional coefficient and the integral coefficient have been selected based on the trial and error technique to get the optimal values of the modulation ratio m. The output of PI controller stage acts as the input to the PWM generation program as shown in Fig.6.
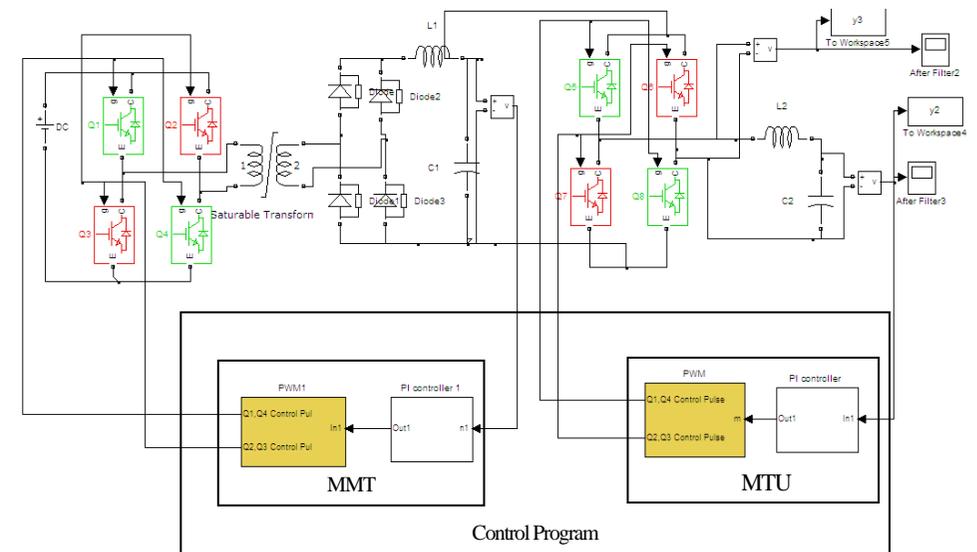

Fig. 6 MATLAB Model of Inverter Power Supply

4.2 PWM Generation Program

The standard method for generating PWM pulses by using a microprocessor or DSP is to utilize one of the built-in PWM modules. In our model, S function block is used to compile the embedded system software to control DC/DC and DC/AC circuits. C programs implements the operations of the microcontroller control units, that is, MMT which controls the generation of the PWM pulses in the DC/DC and MTU which controls the generation of the PWM DC/AC stage. These programs are embedded into the S

function block as shown in Fig.6. Here, the S Function is a computer language description of the Simulink block written in MATLAB, C or C++ [10] The input of the C program becomes the output of the PI control stage which is the modulation ratio. The values of modulation ratio, carrier frequency and the dead time are optimized in the simulation.

5. Experimental Results

The validity and usefulness of the MILS environment constructed is verified by comparing its results with the experimental results in the actual device. As shown in Fig.7, actual prototype of inverter power supply has been fabricated using Renesas SH microprocessor and the embedded software is implemented manually. The input DC voltage is 24V and the target AC output is 100 RMSV with frequency of 50 Hz.

Fig.7 Actual Inverter Power Supply Device

5.1 Comparison of Output AC

The parameter values which are optimized in the developed simulator are almost the same as those in the embedded program of the actual inverter power supply. Here, the parameters include the PI coefficients, the value of modulation ratio, the dead time value and the device parameters of electrical circuits. This fact shows that the embedded program and the hardware developed heuristically is almost optimal.
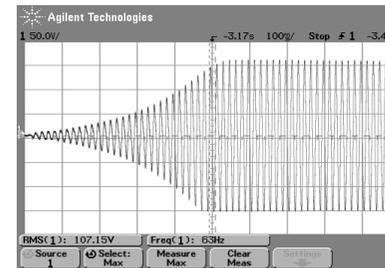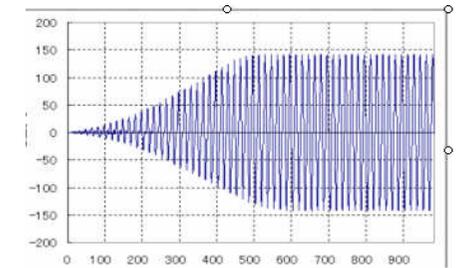

Fig.8a   Actual AC Outputs

Fig.8b   Simulated AC Outputs

Fig.8a shows the AC outputs of the actual prototype, and Fig.8b shows the simulated AC outputs of the developed simulator. By comparing the results in both figures, it can be seen that the shapes of the waveforms are almost identical. Then, we can conclude that the developed models can simulate the actual prototype in a good way.

5.2   Pure Sine Wave Output Voltage and Frequency

Fig.9 and Fig.10 show the actual sin wave output and the simulated sin wave output respectively. Comparing the two waveforms, it can be seen that the results obtained by the developed simulator are in a good agreement with the actual results for both of the frequency and the voltage values. So the developed model can accurately model the actual prototype. Moreover, the developed MILS environment is good to optimize the parameters of embedded programs.
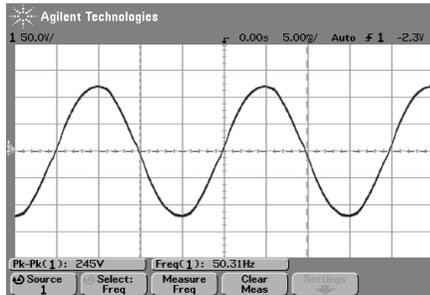
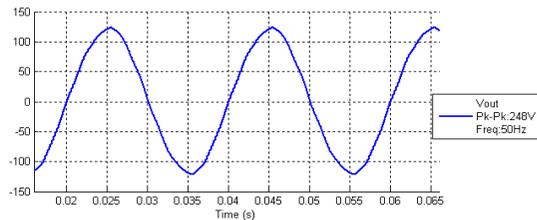Fig.9 Actual Sin Wave Output of Inverter Power Supply

Fig.10 Simulated Sin Wave Output of Inverter Power Supply

6. Conclusion and Future Work

This paper presents model in the loop simulation of the inverter power supply as the first step of applying the model based design technique using the MATLAB and Simulink environment. The validity of the suggested models is tested by comparing them with the actual inverter power supply. The developed model was shown to be well in agreement with the experimental results. This method can be used to optimize the software parameters before the actual design. Moreover, the models can be used to study and analyze the behaviors of the system which meet the challenges of designing the digital control system. The results show that the suggested models are promising and the models can be useful for optimizing the performances in developing the embedded software.

Acknowledgments

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