Design , Implementation and Testing of SPWM Inverter on dSPACE Platform

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Abstract: SPV based system mostly requires an inverter to deliver ac power at the consumers end. This paper presents development of a prototype of a three-phase bridge inverter for SPV applications using dSPACE 1104 hardware Real Time interface with Matlab/Simulink software. Real time Simulation environment could be obtained through dSPACE Platform in conjunction with Matlab/Simulink. In such a system the three-phase inverter model is developed in Matlab/Simulink. A current control strategy is used to generate the PWM pulses in real time using dSPACE 1104 software hardware interface. Instantaneous voltage and current signals of the load side are fed to the control block. The real time pulses generated are then used control the power devices through proper driver circuits. The system is implemented in software and hardware interface by setting an inverter prototype and the results are presented.
Keywords: dSPACE 1104, SPWM, Three-phase inverter, SPV, RT Simulation.

I. INTRODUCTION

Non-conventional energy sources are the only alternative energy source which requires to be harnessed to the utmost level due to diminution of fossil fuels putting entire power industry at stake. Among the non-conventional energy sources solar photo voltaic (SPV) based power generation is currently one of the prime areas in the field of renewable energy resource [1]-[5]. Solar energy being an abundant source of energy, it is by far used mostly to generate electric power to be available to the grid in grid connected systems or may even work in isolated micro grids. As these systems require an inverter to produce ac voltages the quality of power available is a matter of concern for the power industry people. Maximum power tracking from the PV unit, control strategy adopted for the inverter functioning to get lower harmonics at the output utility and subsequent filtering of the ac output are the important areas of research.

The nature of output voltages obtained at the ac side terminals of the inverter is one of the main areas of concern, as it is the ac output voltage may be connected to the grid or in a standalone system may be used as power supply to various equipments. Thus the lesser the harmonic content in the voltage waveforms i.e lower the % THD improved quality of supply is ascertained [6]. As pulse width modulated inverters are the ones which can deliver better voltage and current waveforms with improved power factor. These inverters demand very fast and complex control strategies which are quite difficult to achieve. Thus faster digital controllers have taken over analog ones to achieve lesser harmonics, near sinusoidal waveforms from an inverter the researchers have been trying with various controllers to generate control pulses for driving the power semiconductor devices. Due to fast and complex switching of the power devices analog controllers based on IC's and analog components are lesser used although they have low cost, simpler circuitry and reliability. Sophisticated high end controllers such as digital signal processors (DSP), microcomputers and field programmable gate arrays (FPGAs) [7]-[9] used for their high speed operation and ability to perform complex control algorithms. The quest for better and faster controllers to achieve high degree of accuracy and lower total harmonic distortion in the output voltage waveforms has been still a challenging area of research.

The graphical object-oriented package with the dSPACE system helps in developing complex control systems which are easy to implement involving online measurements, sensors and monitoring of different electrical parameters. Because of its versatility dSPACE based systems are becoming immensely accepted as a controlling platform in recent times. Some application areas are automation systems, car manufacturing electric traction etc. The dSPACE control platform used in power electronics offers a wide variety of options so it is used in developing control strategies for generating switching functions for the power switches of the three-phase bridge inverter.

A current controlled PWM technique is implemented as a control algorithm of the three-phase inverter in this paper. The ac load side voltages and currents are fed as input to the controller. Maximum power tracking is implemented in the PV simulator which is used to deliver similar characteristics as that of an actual solar cell. A Matlab Simulink model is developed in Matlab Simulink. This model is run offline to observe its various results which are desired of it in physical world. Secondly, an .sdf file is built. In the third step, ADC and DAC channels available in the Sim Power Systems Library of the dSPACE platform are used to link the developed model with the real inverter. The Control Desk software is the helping tool in measurements and plotting of real time data or waveforms. Simulation is done in Simulink/MATLAB software using blocksets of the SimPower System and dSPACE RTI1104 (Real-Time Interface) blockset libraries. dSPACE platform is ideal for hardware prototyping and developing systems for cost-sensitive rapid control implementation. It is specially designed for the development of high-speed multivariable digital controllers and real-time simulations in various fields [10].

II. REAL TIME INTEFACE CONTROLLER BOARD DS1104

The internal structure of dSPACE controller board is shown in Fig. 1. The connecting link between MATLAB/Simulink inverter model and the real time hardware is provided by dSPACE controller board which forms the main component of the system [11]. Main inbuilt exclusive interfaces in dSPACE DS1104 controller platform and MATLAB Simulink are DS1104ADC, DS1104DAC and DS1104BIT_OUT_CX. MATLAB/Simulink Real-Time-Workshop (RTW) function may be employed to convert the interface blocks to the C-code automatically [9]. This code is finally compiled by a compiler and linked to the real-time dSPACE DS1104 processor board. A graphical user interface (GUI) is also incorporated in DS1104. This GUI is referred here as Control Desk which helps in instantaneous testing and measurements used to observe the performance of the real inverter hardware set-up. [9]. Deadbeat controllers, voltage controlled SPWM etc. have been implemented on dSPACE DS1104 control platform; although here a current controlled pulse-width modulation is implemented in synchronous reference frame. Digital proportional integral (PI) controller is also another strategy to obtain better quality voltage waveforms at the output of the inverter. Also PI controllers designing is a complex work using analog components but a digital platform such as DS1104 controller board interconnects the Simulink designed PI controllers to the real world. Real-Time Workshop' (RTW) feature inbuilt in MATLAB/Simulink environment is employed to implement a current control strategy. Once the model is built and successfully run, the model is built to generate its equivalent C-code and simultaneously linked to the real inverter hardware. This simplicity of dSPACE DS1104 makes it a suitable tool for researchers and engineers. To get the output waveforms in real time some special blocks are to be inserted in the simulink model; the dSPACE input-output (I/O) library blocks. These blocks are namely: analog-to digital converter (ADC) units, DS1104ADC, bit input-output (I/O) unit, DS1104BIT_OUT, and 3-phase PWM generation unit, DS1104SL_DSP_PWM3. The block diagram of dSPACE DS1104 in Fig. 1 consists of a main processor PowerPC603 64-bit floating-point processor runs at 250MHz, and a slave 16-bit DSP subsystem based on the TMS320F240 DSP microcontroller. DS1104 and also its other variants such as DS1103 are used mainly for building of prototypes as a research tool for developing real complex control algorithms. Its special feature of software and hardware linkage enables it to control multiple switches in a very effective and simple error free manner.

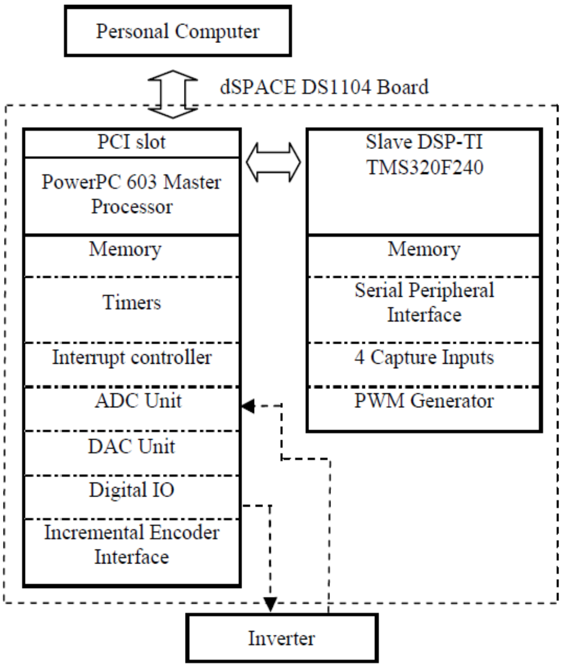

Fig. 1 dSPACE controller board

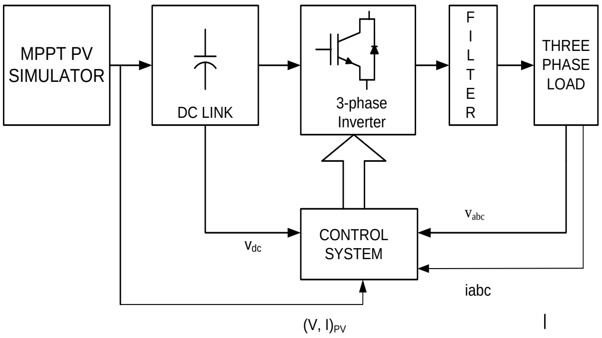

Fig.2 System Control

III. Current Control Strategy

The control block of the system is shown in Fig.2. The control system involves generation of control pulses for the six power devices in the inverter circuit. The generation of the control pulses is entirely done in the Matlab Simulink and is linked to the physical inverter IGBT/MOSFET's through digital signal processing tool board i.e dSPACE 1104. The solar power is trapped in solar cells and maximum power tracking is achieved by MPPT algorithm. The control algorithm is based on the inputs: the dc link voltage, the inverter output voltage, current, voltage and current of the PV simulator for maximum power point tracking. The current control strategy is elaborated in Fig.3. The error in dc bus voltage obtained from the difference of dc reference voltage and the sensed actual dc link voltage. The entire system is simulated firstly in Matlab Simulink to judge the performance of the inverter. A steady dc link voltage is maintained by the controller.

Assuming the line voltages at the inverter load side terminals to be purely sinusoidal and balanced three-phase AC voltages, the amplitude of this voltage can be obtained from the three line-to-line voltages v_{ab}, v_{bc}, v_{ca} and thus can be expressed as:

$$V_{t(ac)ref} = \sqrt{(2/3)(v^2{}_{ab} + v^2{}_{bc} + v^2{}_{ca})} \quad (1)$$

The quadrature component of desired reference output ac side current is computed from the voltage error which is difference between the desired terminal voltage V_{acref} and $V_{t,,}$ the measured voltage at nth instant of the AC source terminal computed from equation in (1). This voltage error $V_{er(n)}$ at the nth sampling instant is given in (2),

$$V_{er(n)} = (V_{acref} - V_{ac}) \qquad (2)$$

The reference quadrature component of current is given by,

$$I_{qref(n)} = I_{qref(n-1)} + K_{pa}\{V_{er(n)} - V_{er(n-1)}\} + K_{ia}V_{er(n)} \qquad (3)$$

K_{pa} and K_{ia} in equation (3) are the proportional and integral gain constants of the outer PI controller (controller 'a'). $V_{er(n)}$ and $V_{er(n-1)}$ are the voltage errors at nth and (n-1)th instants. $I_{qref(n-1)}$ is the quadrature current component at (n-1)th instant.

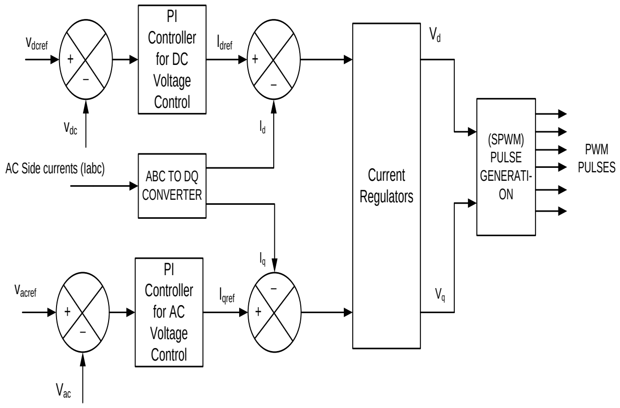

Fig.3 PWM Generation

The q-axis current of the system is derived after sensing the three-phase ac side load currents and converting them to d-q currents by Park's transformation. Thereafter the I_{qref} and the calculated q-axis source current are fed into a current controller block as shown in Fig.2. The current error at nth instant is calculated as,

$$I_{qer(n)} = (I_{qref} - I_{q(n)}) \qquad (4)$$

This current error is processed through a inner PI controller to generate the d-axis desired voltage reference $V_{q(n)}$ given as below in (5),

$$V_{q(n)} = V_{q(n-1)} + K_{pb}\{I_{qer(n)} - I_{qer(n-1)}\} + K_{ib}I_{qer(n)} \qquad (5)$$

K_{pb} and K_{ib} are the proportional and integral gains for the inner PI controller (controller 'b') of the current control block.

To maintain the DC bus voltage at the reference DC bus voltage level, the DC bus voltage error is computed as in (6) and this error being again fed to a PI controller block.

$$V_{dcer(n)} = (V_{dcref} - V_{dc(n)}) \qquad (6)$$

From the DC voltage error obtained at any instant i.e sampled at 'n', the requisite in-phase or active current component $I_{dref(n)}$ at 'n th sample time can be obtained as,

$$I_{dref(n)} = I_{dref(n-1)} + K_{pa}\{V_{dcer(n)} - V_{dcer(n-1)}\} + K_{ia}V_{dcer(n)} \qquad (7)$$

K_{pa} and K_{ia} are the proportional and integral gains for the inner PI controller of the current controller. The d-axis source current at the nth instant $I_{gd(n)}$ as obtained after Park's transformation from the sensed three-phase currents of the AC source, is used to get the d-axis current error $I_{der(n)}$ given as in (8),

$$I_{der(n)} = (I_{dref(n)} - I_{d(n)}) \quad (8)$$

$I_{dref(n)}$ is the calculated values of reference current at the nth instant.

$$V_{d(n)} = V_{d(n-1)} + K_{pb}\left\{I_{der(n)} - I_{der(n-1)}\right\} + K_{ib}I_{der(n)} \quad (9)$$

The d-axis voltage is then obtained according to (9) in the PI controller as in Fig. 2. K_{pb} and K_{ib} are the proportional and integral gains for the inner PI controller..

IV. MATLAB SIMULATION

Initially a MATLAB Simulink based model is created to establish the correctness of the algorithm. Based on the control algorithm proper control signals derived are obtained in Real-time by the DAC blocks available in the dSPACE platform. These switching signals are utilized to drive the power devices of the proposed inverter using the control theory as explained previously. MATLAB/Simulink model was developed using components from the Sim Power systems blockset. A discrete mode simulation was considered with a sampling period of 5 µs. The simulation model is shown in Fig. 4 shows. A battery equivalent was taken as the output from a PV based energy source [12]. A 100 V dc input voltage was taken and later a PV simulator was used in MATLAB/Simulink to run the complete system. MOSFET's are used here as the power devices.

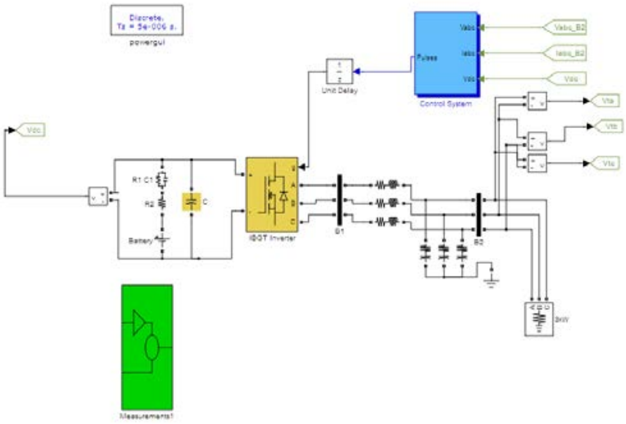

Fig. 4 Simulink model in MATLAB/Simulink

The inverter is tested with resistive loads is used as the output of the inverter. The three phase line voltages are measured and fed to the measurement block to observe the waveforms in the oscilloscopes. Three-phase voltage current measurement block is used for controlling and measurement purposes.

V. EXPERIMENTAL VALIDATION

The MATLAB/Simulink model dSPACE DS1104 control board using ADC and DAC interfaces is shown in Fig. 5.

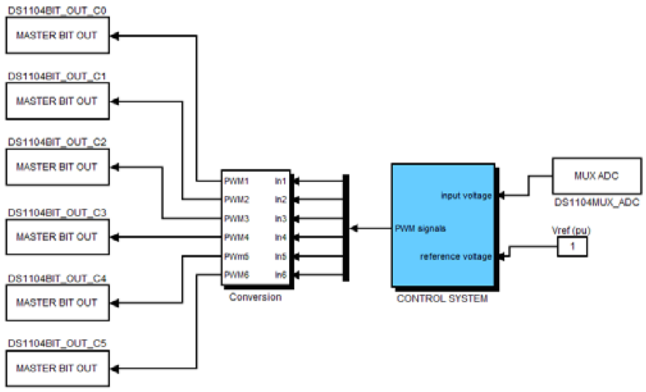

Fig. 5 dSPACE DS1104 Simulink model

Fig. 6 Dual MOSFET module with driver circuit

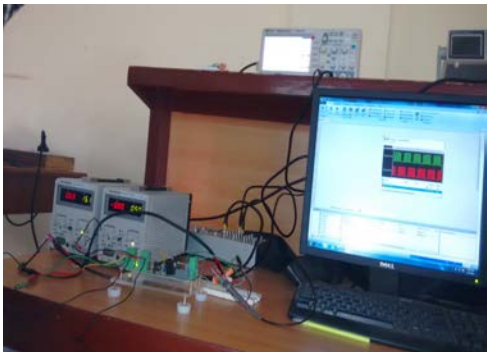

Fig. 7 Testing of circuit in dSPACE DS1104

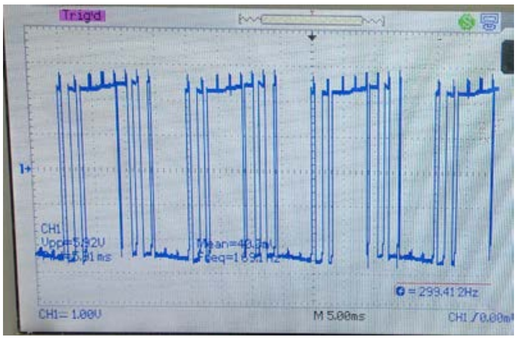

Fig. 8 Output voltage of inverter before filtering

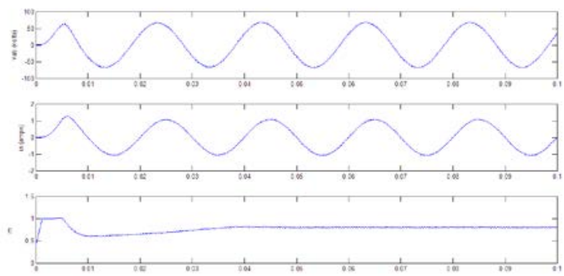

Fig. 9 Voltage, current and modulation index

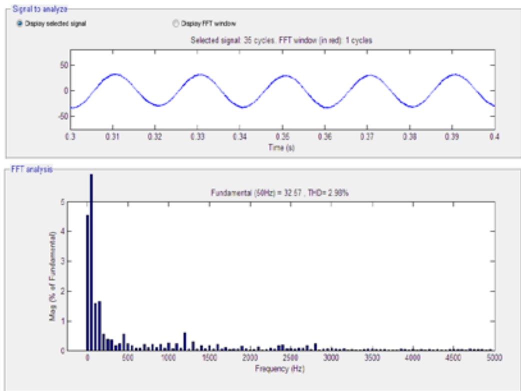

Fig. 10 FFT Analysis in simulation

The ADC block DS1104MUX_ADC is used for reading the analog signals dc bus voltage, inverter output voltage and current and converting to digital signals. DACH1 to DACH6 are used to get the analog output PWM pulses of the digitally generated PWM signals. The PWM signals are obtained at the terminals PWM 1 to 6 outputs after suitable data conversion.

The simulation model was tested in the lab using dSPACE DS1104 digital signal processing board on a MOSFET based inverter and a resistive load using suitable filters. The digital signal generated from the simulink model was fed to the dSPACE board through parallel busses. Fig.7 shows the experimental hardware set-up and Fig. 6 shows the dual Mosfet module along with associated driver circuits used in the experiment. Fig. 8 shows the PWM voltage waveform before filtering.

VI. CONCLUSION

The paper describes the prototype development of an inverter system applicable in SPV based systems. The specialty here is the control system which is current controlled PWM and is implemented using MATLAB/Simulink. The link of the MATLAB/Simulink with the real inverter is done with the help of dSPACE DS1104 controller board. DS1104 control board using ADC and DAC interfaces. The ADC block DS1104MUX_ADC is used for reading the analog signals whereas DAC interfaces helps to take the pulse out to subsequently drive the IGBT's. The result obtained is near to the expected ones. Further development process may be continued to reduce harmonics, regulation, waveform based on the actual application environment like type of load , local solar insolation , Module characteristics System with storage battery or without storage battery , Grid Connected , Hybrid or Stand alone System.

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