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Development of Hardware in Loop Simulation of Grid Connected Photovoltaic System

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Abstract

This paper describes an ideal topology for inverters in a grid connected photovoltaic (PV) system. The Multistring inverter topology will improve the reliable operation of the Photovoltaic (PV) system because of independent control of each string will enhance the efficiency of the system. An efficient voltage control scheme is presented to control the Maximum Power Point Tracking (MPPT) and the inverter. The three phase two level voltage source inverter (VSI) has been used to validate the concept of Multistring. The simulation results have been presented to verify the proposed topology. An experimental prototype has been developed in the laboratory and dSPACE DS1103 is used to generate the signals for real time implementation.

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Keywords: PV, MPPT, Multistring, VSI, dSPACE

1. Introduction

During the last few years the installed capacity of grid connected photovoltaic systems have been drastically increased all over the world because of the increase in cost of energy generated by the conventional power plant and at the same time cost of photovoltaic modules has been reduced to generate the clean energy [1]. Grid Connected Systems have been classified into small scale (upto 2 kW), medium scale (2 – 500 kW) and large scale systems

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(more than 500 kW) based on power ratings. Medium Scale grid connected systems have three different inverters they are Central, String and Multistring Inverters [2]-[4].

Central Inverter consists of enormous number of solar panels coupled in series or parallel to the one single inverter. The drawbacks of this type of inverters are if they are any mismatches in PV panels the entire system will get affected and also the installation cost of the system is very high. String Inverters are better when compared to Central Inverter because of one inverter is connected to each string and the separate MPPT Algorithms in order to surge the capacity of the system [5]-[7]. The drawbacks of String Converters are which can be applicable to certain kilowatts level because the cost of the system is very high due to the large number of inverters. Multistring Inverters are the ones which is capable of combining the advantages of both the Central and String Inverters it has the advantage of having separate DC-DC converter intended for each string which will leads to generate extreme power and it can be applicable for Megawatt system because of the flexibility provided by the system one can easily increase the capacity of the system by connecting one additional string without making too many changes and the cost of this type of inverter is high but the amount of energy generated will compromise the cost [8].

One of the most consistent topology in use for numerous purposes is the three phase 2-level VSI arrangement. Due to its easiness, dependability and lustiness it has been used over the years in the area of electrical drives and in the industrial zone this topology is very popular. In general, most of the VSI topologies are used in medium scale systems based on MOSFETs and IGBTs. But in VSI there is a possibility of having expensive filters because the switching frequency has been limited [9]-[10].

In this paper the multistring topology has been described based on two level VSI the parameters of the systems are analysed with the help of simulations and the experimental prototype has been developed in the laboratory in order to validate the system. The proposed topology can be used for a medium capacity load, while improving power quality and efficiency. As the converter structure is very flexible and modular, it allows independent control goals.

The following section describes the complete system description and the control strategy adopted and the simulation and the experimental results and finally discussion has been made based on the results.

2. System Description

The block diagram of the projected system is shown in Fig.1. It comprises of two PV strings which have the capacity of 10kW. One string has 20 panels 4 panels are connected is series and 5 modules are connected in parallel to get the capacity of 5 kW and it is linked to the boost converter through the capacitors. Then the two boost converters are coupled in sequence to increase the DC link voltage. The conventional three phase two level voltage source inverter (VSI) is used for connecting to the grid. In most of the industries still they have used the two level VSI because it provides the greater flexibility for reliable operation of the system.

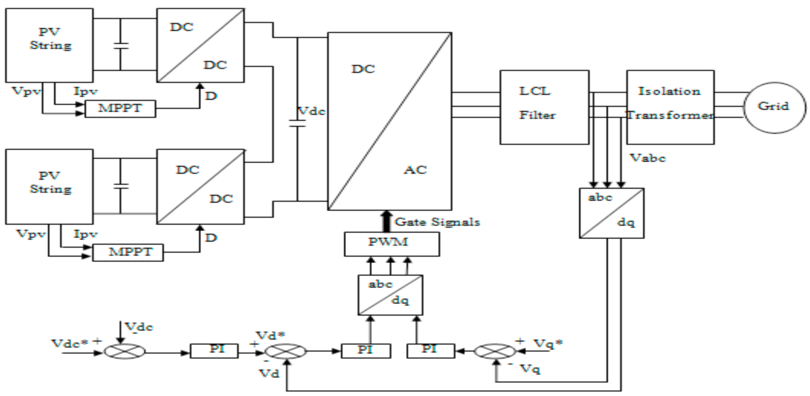


Fig. 1. Block Diagram of Multistring Inverter for Medium Scale Grid Connected System.

The Isolation transformer is used in order to isolate the inverter from the grid. Whenever there is enough sunlight and temperature the inverter will feed the local consumer load and excess power is feed through the grid and if there is scarcity of sunlight then the grid will deliver the power to the consumer load.

3. Control Strategy

There are two control strategies in the proposed system. One for MPPT Control and the other one is the Inverter Control. Because the MPPT part is totally decoupled from the power control of the grid portion, both the control strategies can be projected and carried out individually.

3.1. MPPT Control

The function of MPPT control is to sense the voltage and current from PV modules and it has been given as input to the MPPT algorithms. Numerous methods of MPPT algorithms have been proposed based on the application. In this system one of the most used algorithms Perturb and Observe is implemented based on the previous and present values of voltage and current then it will generate the duty cycle and this signal is given as triggering signal for boost converter.

3.2. Inverter Control

The dc link voltage at input side of VSI Inverter, and grid interface control with active and reactive power are operated with conventional voltage oriented control.

The inverter voltage is taken as feedback and the three phase voltage has been converted into d, q components by using three phase to two phase transformation.

Then the d axis and q axis voltage components are compared with position of d axis and q axis components. The reference d axis voltage component has been calculated by subtracting with the dc link voltage error is passed through the pi controller where the error is minimized and it has taken as the reference value. The reference q axis voltage component has been put as 0 for maintaining the unity power factor. The comparator is used to compare the signals of d axis and q axis voltage components by using reference and the calculated values and then the error is generated which has been passed through the PI controller and the new values of d and q axis component has been calculated. Then again it has been converted to three phase quantities by using two to three phase transformations. Then the three phase quantities are given as input to PWM modulator which will provide the gate pulse for the inverter.

4. Simulation and Experimental Results

The proposed system has been simulated in Matlab/Simulink. The performance parameters of entire system have been analyzed. The parameters used for simulation are shown in Table 1.

Table 1. Parameter used for Simulation.

Parameter	Rating
PV Panels	250 W
Boost inductor	25uH
DC Link Capacitor	2200uF
Filter Inductor at inverter side	15mH
Filter Capacitor	100uF
Filter inductor at grid side	5uH
Switching Frequency	2 kHz
Output Frequency	50 Hz
Grid side Voltage	415 V
Sampling time	50 us

The Voltage, Current Power and DC link Voltage of boost converter waveforms are shown in Fig.2 where the total capacity of the PV string is 5 kW. The MPPT operation came into effect at time T= 0.05s from where the system settles to its peak point for static conditions at 25°C and 1000 W/m^2.

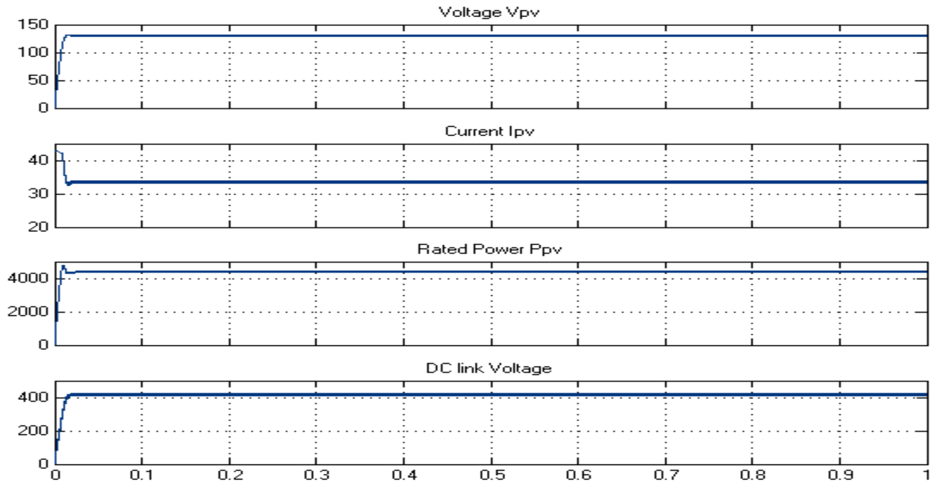


Fig. 2. Voltage, Current and Power waveforms of one PV String under static conditions

The Voltage and Current of the three phase inverter waveforms are shown in Fig.3 for static conditions.

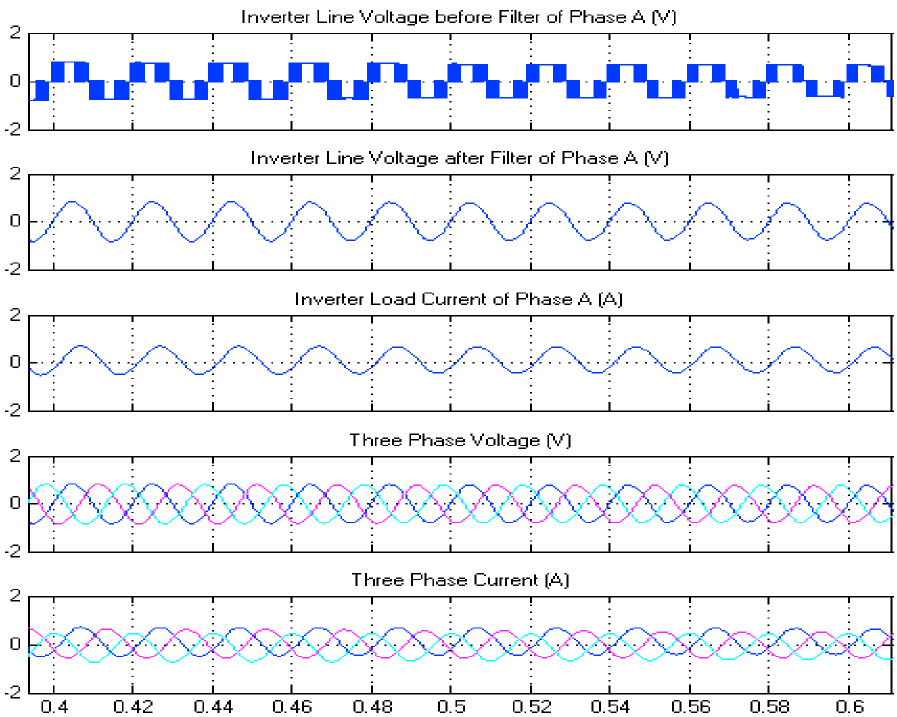


Fig. 3. Voltage and Current waveforms of Inverter under static conditions

The Voltage, Current Power and DC link Voltage of boost converter waveforms are shown in Fig.4 for dynamic test conditions where the temperature is fixed at 25°C and the irradiation value is kept at 500 W/m^2 till T=0.5s then it is increased to 1000W/m^2.

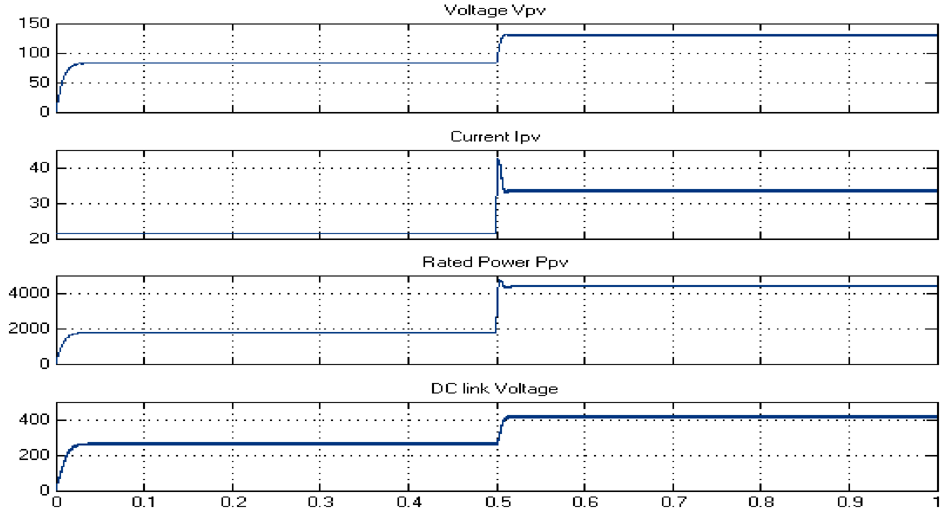


Fig. 4. Voltage, Current and Power waveforms of one PV String under dynamic conditions

The Voltage and Current of the three phase inverter waveforms are shown in Fig.5 for dynamic conditions where the voltage and current are changed when irradiation changes from 500 W/m^2 to 1000 W/m^2.

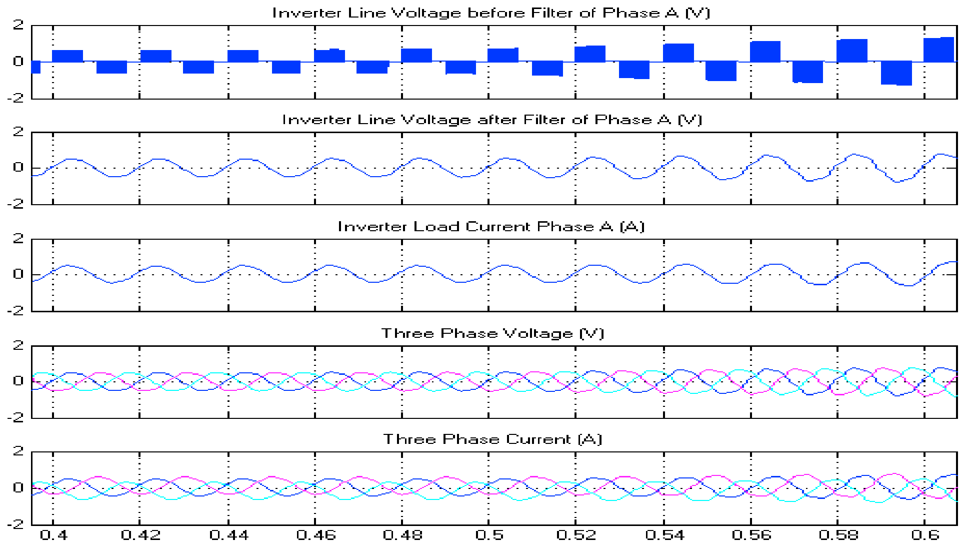


Fig. 5. Voltage and Current waveforms of inverter under dynamic test conditions

The DC link Voltage of 2L-VSI is displayed in Fig.3. Initially voltage reaches its peak point and then it settles on steady state in order to deliver the efficient power because for proper operation of inverter depends upon the constant DC link Voltage.

The duty cycle of boost converter has been based on the MPPT algorithms. The inverter current and voltage signals are shown in Fig.4. Inverter line voltage before filter is displayed based on harmonic distortions the LCL filter has been designed in order to get the pure sinusoidal voltage and current and all the quantities are expressed in p.u.

The three phase waveforms of the voltage and current of the three phase inverter is shown in Fig.5. Current waveform shows some distortions because of the load variation

The Harmonic analysis of the inverter voltage and current has been done through the FFT transforms and the output are plotted in Fig. 6 and Fig.7.The THD of inverter voltage is 1.92 % and for current is 2.61% and the dominant lower order harmonics are not present.

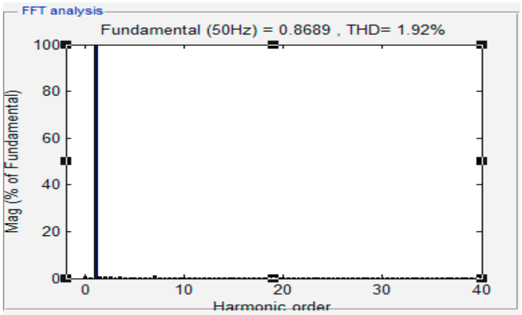


Fig. 6. Total Harmonic Distortion of Line- Line Inverter Voltage

So as per IEEE standard the THD of voltage and current has to be less than 5%.So the proposed system has been satisfiedd the IEEE standards,

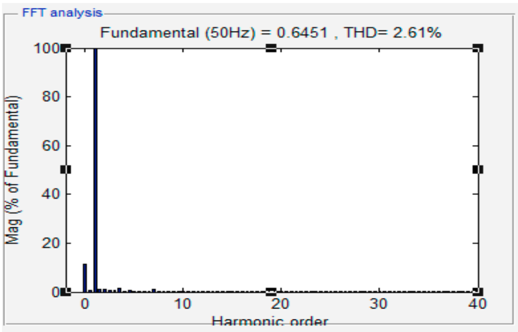


Fig. 7. Total Harmonic Distortion of Load Current of Inverter

A hardware prototype of the three phase VSI is developed in the laboratory to carry out the tests is shown in Fig.8. The VSI has been made using the MOSFET module through dc-link capacitors at the input side are taken as as the source for the inverter. The control algorithm is implemented over dSPACE real-time interface DS1103.

Table 2. Parameter used for Hardware Implementation.

Parameter	Rating
DC link Voltage	30 V
Switching Frequency	2 kHz
DC Link Capacitor	1100uF
Load Resistance	20Ω

The parameters which are used for testing are shown in Table 2. The interface among MATLAB/Simulink & digital signal processor (DS1103 of dSPACE) permits controller algorithm has been dumped into the processor through a PPC750GX core and on-chip peripherals. The master bit I/O is used to create the six gate pulses and three ADC converters are used for the sensing the load voltages. An optoisolated interface board with TLP 250 optoisolator is used to separate the entire DSP master bit I/O.

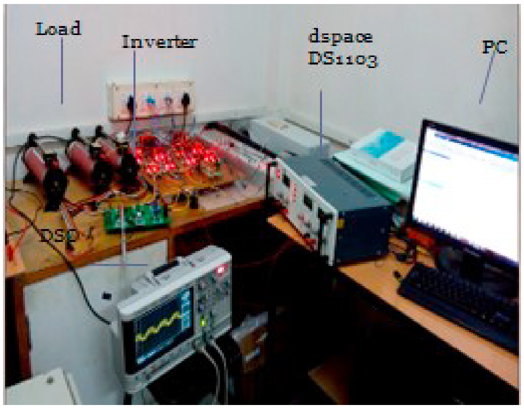


Fig. 8. Experimental Setup of 2-level inverter prototype

Instead of PV source the laboratory power source is used to carry out the test in the prototype and the rheostat has been used the load. The waveforms are recorded in Digital Signal Oscilloscope (DSO). The simulation model is interfaced with dSPACE DS1103 and the Hardware in Loop Simulation has been done through Control Desk Real time Implementation where the switching pulses are generated and it is shown in Fig.9.

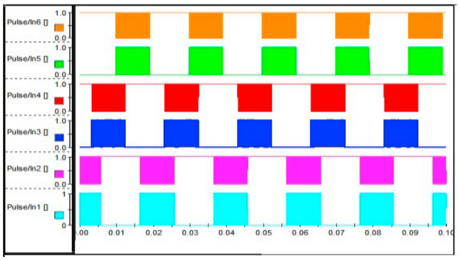
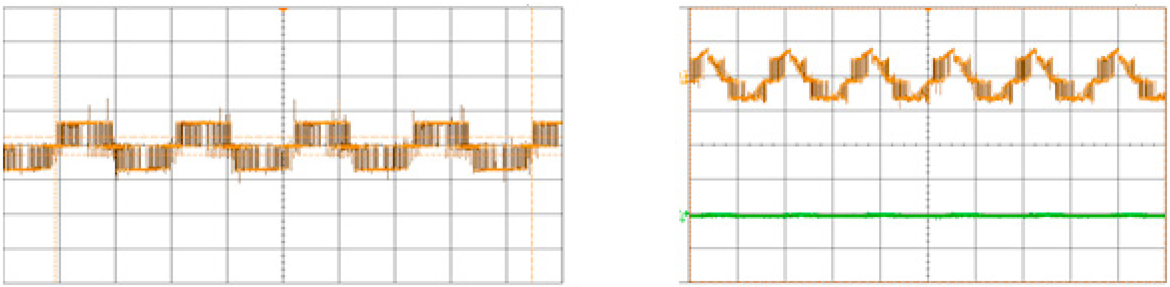


Fig. 9. Generation of Switching Pulses through Hardware in Loop Simulation



(a) (b)

Fig. 10.(a) Inverter Voltage (Line-Line) – Voltage 30 V/div, 5 ms/div,(b) Inverter Current – Current 3 A/div, 5 ms/div

The Line-Line voltage waveform of the inverter is shown in Fig.10 (a). The scale has been considered has 30 V/div. So in order to check the performance of the inverter 30 V supply has been fed to the inverter through the DC link capacitor. The Load Current of the inverter is shown in Fig.10 (b) and the scale has been taken as 3 A/div. The three phase resistive load has been connected the inverter of 20Ω capacity. Due to the unbalanced load the current waveform has been distorted. Therefore the prototype developed in the laboratory has been tested for some fixed power supplies and it has shown very good performance.

4. Conclusion

In this paper, the real time implementation for grid connected system has been presented. The MPPT and inverter has been controlled efficiently by using the proposed voltage control scheme and also increase the overall efficiency of the system. The three phase two level voltage source inverter topology has been developed in laboratory and also interfaced with the dSPACE by creating the hardware in loop system in order to implement the system in real time.

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