Control of DC-DC Converter and Inverter for Stand-alone Solar Photovoltaic Power Plant

K. Anjali, K.R. Lekshmi, P. Ramesh and T. Sreejith Kailas

Abstract – *Solar energy is one of the most promising sources of energy for the future world. Being clean and renewable source energy, a lot of research is happening across the world in the solar energy area. Solar photovoltaic is considered to be the best means of tapping solar energy. Power electronics is considered to be the driving technology for energy conversion schemes from solar photovoltaic. In this paper an efficient energy conversion scheme for a stand-alone solar photovoltaic power plant is presented with details on control schemes. Simulation studies and laboratory proto unit are also presented.*

Keywords— *Digital Signal Processor (DSP), Discontinuous Pulse Width Modulation (DPWM), Field Programmable Gate Array (FPGA), Predictive control, pulse width modulation (PWM) strategies, Space vector pulse width modulation (SVPWM)*

I. INTRODUCTION

A stand alone photovoltaic power plant is usually used in locations where there is no grid connectivity. Such power plants may be used in a smart grid environment considering the energy economics. The stand-alone solar photovoltaic power plant generally consists of an input DC-DC converter, output inverter, filter, transformer and battery bank for storage connected to the intermediate DC link. The variable DC from the output of the solar photovoltaic array has to be converted into a fixed DC and this is done by the input DC-DC converter. The DC-DC converter proposed in this paper is of the boost topology. Battery and battery management become subsystems of such power plants. The inverter is used to generate regulated AC supply at the output so that loads can be connected on the AC side. A transformer is provided at the output to match the voltage and to provide isolation. Moreover the transformer acts as output impedance of the power plant which will limit the fault current. The transformer also attenuates DC injection from the inverter if any. Figure 1 shows the single line diagram of the solar photovoltaic power plant.

The inverter used is a 3phase 6pulse inverter, whose control strategy implemented will provide stiff control of

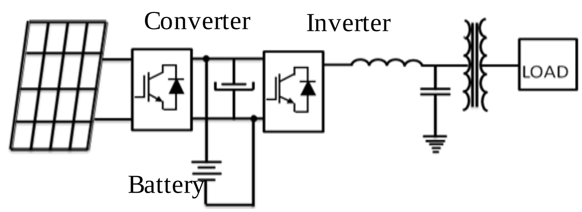

Fig.1. Scheme of stand-alone photovoltaic

voltage and frequency at the output. A detailed analysis is carried out for different PWM strategy used in inverters and variable structure scheme is proposed for higher energy efficiency. A thermal analysis is carried out to study regarding the thermal performance of various PWM schemes and results are presented. All the above schemes are analyzed and validated using simulation and actual experiments on proto PCU. The simulation studies are done using PSIM. The proto PCU is rated for 10kW and the control is implemented using a digital controller developed with DSP and FPGA.

II. INPUT DC-DC BOOST CONVERTER

The input DC-DC converter in boost mode interfaces the input solar PV sources to the inverter. Battery is connected at the output of the boost converter. The battery helps energy storage so that during low solar insolation or night time the battery will supplement the power to the load. In a micro-grid where many power plants are operating in parallel, the battery provides the inertia to the generating system. Its preliminary function is to regulate a constant DC voltage with minimum ripple so that the inverter can be controlled well.

The paper analyses all the subsystems and brings out a practical design with controllers for the DC-DC converter and the output inverter. The DC-DC boost converter is controlled such that the output inverter is fed with a more or less constant DC input voltage at the interconnecting bus. Since the battery is connected to the DC bus battery management is also incorporated in the control scheme of the DC-DC converter. The DC-DC converter also tracks the Maximum PowerPoint in which the photovoltaic array has to operate [1].

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A. Converter control

There are two control methods for DC-DC converter, current mode control and voltage mode control. Current mode control for a DC-DC converter is a two loop system. An additional inner current loop is added to the voltage loop. The current loop monitors the inductor current and compares it with its reference value. The reference value for the inductor current is generated by the voltage loop [2]. It will easier for paralleling of converter even the filter components differ from each other.

Predictive method of current mode control will have the faster step response [3]. Predictive control will generate all the duty cycle in advance based on the reference current and the sensed inductor current, input voltage and output voltage. This method will be simpler than other control methods of DC-DC converter. In the Predictive Digital Current Program Mode control (PDCPM), the inductor current is sampled only at their peak instants. This is achieved by sampling the inductor current of a particular converter immediately after its switch is turned off. The output voltage obtained from predictive control is shown in figure 3

For PDCPM technique outer will be a voltage loop, it will provide better noise rejection. The output of voltage loop is fed to the predictive controller loop. In the predictive controller loop the inductor current at the beginning of the next switching cycle is determined by the inductor current at the beginning of present switching cycle, input voltage, output voltage, duty cycle at the present of switching cycle.

$$i_L(t(n+1)) = i_L t(n) + \frac{V_{in}(t)}{L}Ts - \frac{V_0(n)}{L}(1-d(n))Ts \quad (1)$$

From equation (1) duty ratio can be derived as

$$d(n) = \frac{L}{Ts}\,\frac{i_L(n+1) - i_L(n)}{V_0} + \frac{V_0 - V_{in}(n)}{V_0} \quad (2)$$

From equation (2) the duty ratio can be found in advance. One way to improve the digital control performance is the predictive Control technique. In short the predictive mode of current control increases the speed of the inner current loop.

Voltage controller can be a simple PI controller

B. Interleaved operation of boost converter

Interleaved operation of boost converter is obtained by phase shifting the carrier by 120 degree. Interleaved performance will reduce the ripple in current and voltage thereby reducing the filtering requirements. Carrier waveform of the interleaved operation is shown in figure.2. The major advantage of interleaving is redundancy. The effective peak current will get reduced by a factor of 3 thereby improving efficiency. Since the control action itself is getting corrected

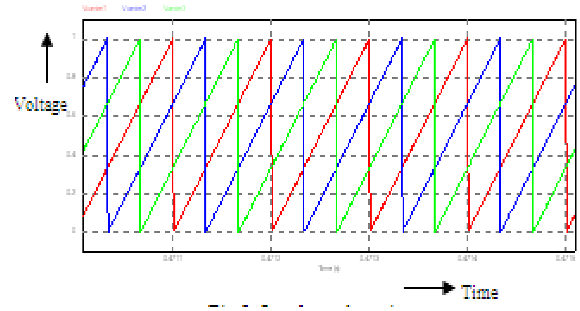

Fig.2. Interleaved carriers

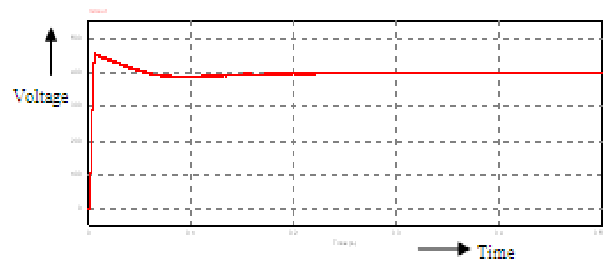

Fig.3. Output voltage obtained from predictive control

thrice, the frequency of the individual converters the dynamic performance of the system also will get improved.

The major benefits of carrier interleaving are increased equivalent switching frequency, high dynamic performances and improvements in reliability. The control strategy in the interleaved condition should take care of current sharing even in transient load variation. This helps in paralleling of dissimilar converters with stiff current control. This requirement is crucial in PV power plants as the capacity increase may be a frequent task.

III. OUTPUT INVERTER

The solar inverter is a critical component in a solar energy system. The inverter is build of switching devices, thus the way in which the switching takes place in the inverter gives the required output. The output voltage need to be regulated at rated voltage and frequency when the load is within limits. The controller has to ensure that the voltage is regulated when DC bus voltage has oscillation within the limits. The control methodology should also ensure that the efficiency of operation is kept maximum. For this the switching losses needs to be minimized with proper selection of modulation strategy

A. Inverter control

The system uses a multi loop control. There will be an outer voltage loop and inner current loop. The control methodology adopts vector control scheme.

The outer voltage controller will take care of the dynamics introduced by the dc bus capacitor. The load current is added as a feed forward term to the capacitor current reference. This improves the dynamics of the voltage controller during load fluctuations. The voltage controller output will be the current to be maintained in the filter capacitor so as to regulate the voltage across it.

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B. Variable PWM strategies of three phase inverter

Inverters will transform the regulated dc voltage into ac form. Inverters are controlled by various PWM strategies i.e. sine triangle PWM, space vector PWM, and the discontinuous PWM.

In the case of sine triangle pulse width modulation, the control signal is a sinusoidal signal. The sinusoidal signal is compared with switching frequency carrier waveform in order to generate the switching signals. The frequency of the carrier establishes the inverter switching frequency and is generally kept constant along with its amplitude.

Space vector modulation (SVM) for three-leg VSI is based on the representation of the three phase quantities as vectors in a two-dimensional (α-β) plane. Space vector modulation came from the fact that time averaging of voltage will give the flux .i.e. Time averaging of voltage will be equivalent to the sinusoidal quantity.

Discontinuous PMW methods have found application in high performance current controlled drives due to their low switching loss characteristics and low current ripple characteristics. In the over modulation region DPWM is the only modulators that maintain high gain. Therefore DPWM is the most beneficial to high power PWM VSI drives. Modern modulation methods were separated into two groups continuous PWM and discontinuous PWM. The waveform quality and switching loss comparison indicated near zero modulation index regions CPWM methods are superior to DPWM methods.

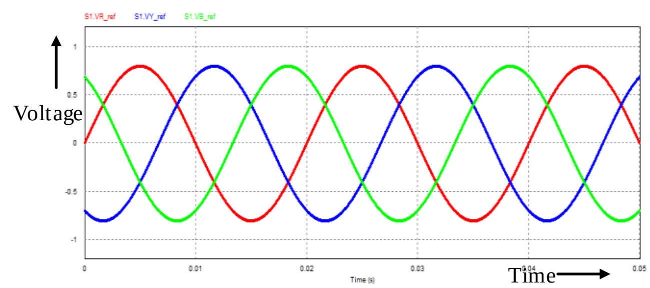

Fig.4. Modulating signal of SPWM

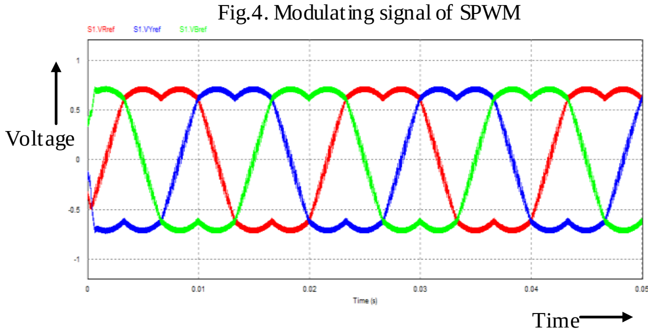

Fig.5. Modulating signal of SVPWM

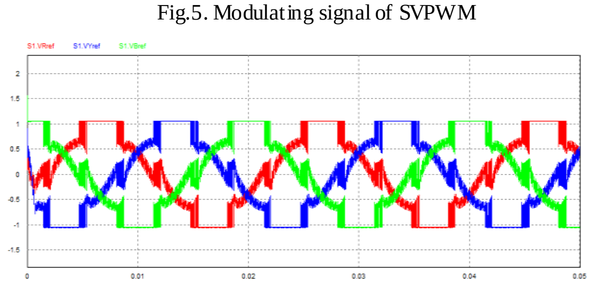

Fig.6. Modulating signal of DPWM

Power Rating(kW)	Psw SPWM(A)	Ptotal SPWM(A)	Psw SVPWM(A)	Ptotal SVPWM(A)	Psw DPWM (A)	Ptotal DPWM(A)
1	46.02	53.9	37.97	45	30.942	38
2	55.91	69.44	45.28	57.03	37.56	51
3	65.5	85.43	52.41	69.79	42.9	62.9
4	74.92	101.42	59.49	82.49	48.5	75.1
5	84.24	117.6	66.36	95.27	53,94	87
6	93.56	133.96	73.31	108.23	53.36	100
7	102.85	150	80.1	121.2	64.3	112
8	112.12	167.02	87.07	134.5	69.08	124
9	120.87	183	93.23	147	74.05	137
10	132.12	202.42	100.75	161.16	79.5	150

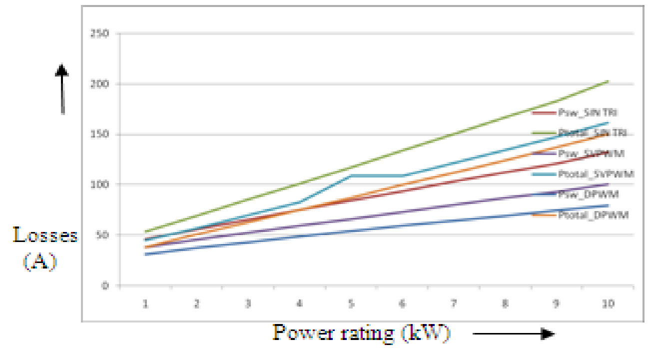

Fig.7. Loss comparison of different PWM methods

C. Loss analysis of different PWM with actual IGBT module

For calculating losses, actual IGBT module PM150CLA060 is used. Losses are in the form of electric current. Thermal analysis will give the transistor conduction losses, transistor switching losses, diode conduction losses, and diode switching loss. If the frequency of IGBT module is 50Hz, the losses results are the average value for an interval of 20ms. If the frequency is set to be same as the switching frequency, the losses in each switching cycle are obtained. Losses are highest in the case of sine triangle modulated three phase inverter. SVPWM have more losses than DPWM technique but less than that of SPWM technique. Loss comparison of different PWM methods is shown in table 1.

IV. EXPERIMENTAL SETUP

The experiments were conducted at NaMPET laboratory CDAC-Trivandrum. The experiments were carried out on a 10 kW Power Conditioning Unit. The specification of the proto unit is given in the table 2.

10 kW sub module has a structure as shown in Fig.8. The proto unit consists of a module having three DC-DC boost converters in parallel and a three phase inverter and a DC bus capacitor.

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TABLE VII. Specifications of Proto Unit

Sl No	Parameter	Value
1.	Open circuit voltage for the solar PV array(V_{OC})	385 V
2.	Switching device	IGBT
3.	Maximum Power Point Voltage(V_{mpp})	290 V
4.	DC bus voltage(output of the DC-DC converter)	400V
5.	Maximum allowable ripple at the output	< 2% of the rated
6.	Input current ripple	<2.5 % of the rated
7.	Input voltage ripple	<1%
8.	Switching frequency of the converter	10 kHz
9.	Input inductor	5mH,50A
10.	Output capacitor and Input capacitor	440µF

Fig.8. Power converter module

V. CONCLUSION

This paper presents simulation studies on DC-DC converter with carrier interleaving, Predictive Digital Current Program Mode (PDCPM) control for realizing the multi loop control strategy in DC-DC converter and various modulation strategies for inverters. All the above are studied in connection with realizing stand alone photovoltaic power plants. The modulation strategies of inverters are compared according to their losses. Experiments are carried out on a 10kW PCU.

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