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A Study of the Grid Connected Transformer-less PV PC

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Abstract - This paper describes control of the grid connected transformer-less type photovoltaic(PV) power conditioning system, which is simpler and more efficient than conventional transformer type systems. With modeling and analysis of PV system, the validity of the control strategy was verified by simulations and experimental results.

1. Introduction

The PV power system consists of PV array and a inverter system. There are three power conditioning systems(PCS) which are derived from the isolation methods. They are : the 60Hz transformer type, the high frequency isolation type and the transformer-less type.

The 60Hz transformer type consists of H-Bridge converter and the transformer. Its output current is controlled by PWM technique. The main circuit and the control type are very simple. Although it can control the reactive power, this type has the disadvantage in weight, size, sound and cost.

The high frequency isolation type consists of PV array, the H-Bridge high frequency inverter, the high frequency transformer, the one phase H-Bridge diode rectifier, a DC reactor, the one phase H-Bridge low frequency inverter and the AC LC filter. The DC voltage of solar arrays is transferred to high frequency AC voltage by a H-Bridge high frequency inverter.

The high frequency transformer doesn't saturate due to transformer output current PWM control. This type is more efficient than the 60Hz transformer isolation but it has complex power circuits and the control algorithm which can be very costly[1,2].

The transformer-less type grid connected PCS consists of DC/DC converter and the H Bridge inverter. The DC/DC converter alternates the transformer. This paper describes full digital control of the more effective and inexpensive transformer-less type PCS by simulations and experimental results.[1,2]

2. Transformer-less type PCS's MPPT Position

The transformer-less type PCS is divided into two type PCSs, DC/DC converter maximum power point tracking (MPPT) type and Inverter MPPT type.

2.1 DC/AC inverter MPPT control

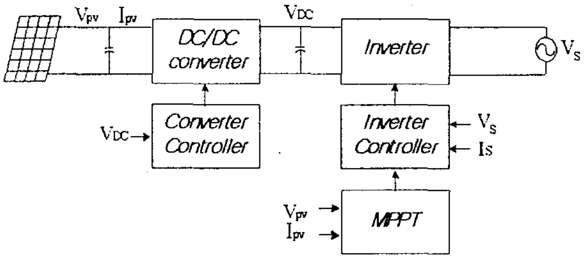

Fig 1. DC/AC inverter MPPT control type

For PCS of this kind, the output current and MPPT are controlled by the inverter. The DC/DC converter controls the DC link voltage only.

2.2 DC/DC converter MPPT control

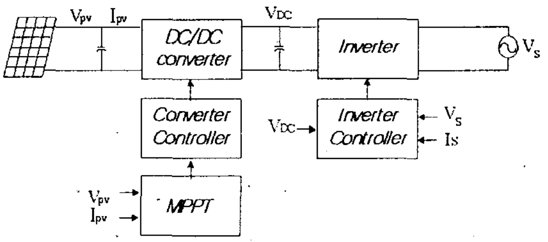

Fig 2. DC/DC inverter MPPT control type

For PCS of this kind, MPPT is controlled by DC/DC converter and the output current is controlled by the inverter. It controls the type with full digital control by TMS320F240 DSP.

3. DC/DC Converter Control Strategy and Simulation

3.1 DC/DC converter control strategy

The DC/DC converter uses the output current and the voltage of solar arrays and making the Maximum Power

Point(MPP) with perturbation and & observation(P&O) algorithm.

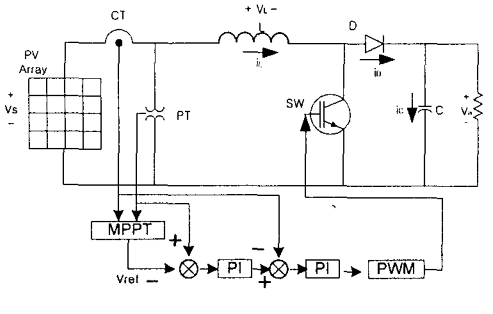

Fig 3. Control block diagram of DC/DC converter

The MPP is controlled by the voltage and the current of DC/DC converter.

3.2 DC/DC converter simulation

The full period of current control is 50 μ sec and voltage control is 500 μ sec similar to the DSP control period.

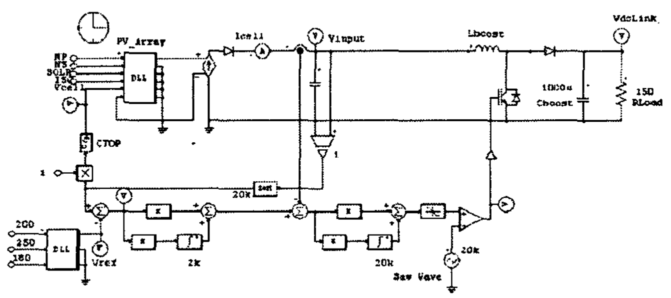

Fig 4. Simulation schematic of DC/DC converter

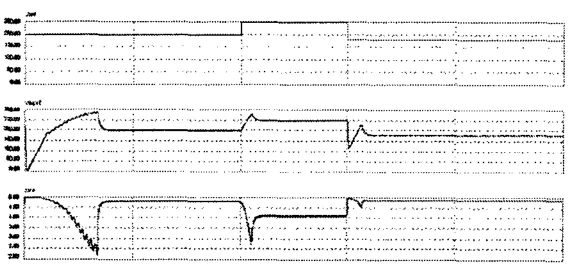

Fig 5. DC/DC converter simulation waveforms

The first wave is the voltage reference wave, secondly the voltage wave, thirdly the current wave. It is visible that the voltage of DC/DC converter is controlled by the input voltage reference made by dynamic linked library(DLL) simulation function which can be transferred to P&O MPPT algorithm.

4. The Strategy and Simulation of the Total System

4.1 PCS system control strategy

The control block describes the overall system of the transformer-less type PCS. The magnitude of the current reference is made by the difference of the DC link part voltage and the reference voltage. It is synchronized with sinusoidal wave of the grid voltage phase. The error of the feedback current and the reference current through the PI controller and make PWM gating signals

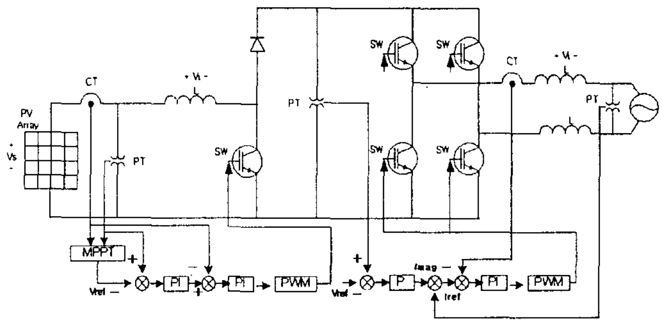

Fig 6. Control block diagram of PCS

4.1.1 Digital phase locked loop strategy

Line notching, voltage unbalance, line dips, phase loss, and frequency variations are common symptoms suffered by the grid connected PCS. Any phase locked loop(PLL) used under such conditions should not only be able to phase lock to grid voltages as quickly as possible. But also maintain lock and provide low distortion output.

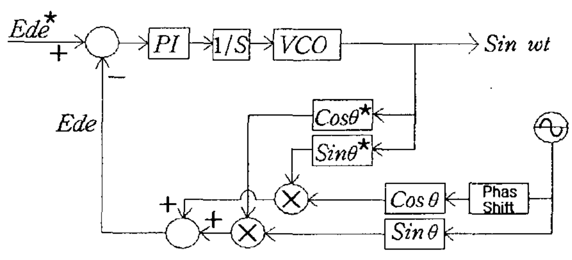

Fig 7. PLL block

This block describes the PLL used in this system.
A simplified control model of the one phase PLL can be developed using the following transformations.

$$\begin{bmatrix} \cos\theta \\ \sin\theta \end{bmatrix} = \begin{bmatrix} Shift & Value \\ Origine & Value \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} Eqs \\ Eds \end{bmatrix} = \begin{bmatrix} \cos\theta \\ \sin\theta \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} Eqe \\ Ede \end{bmatrix} = \begin{bmatrix} \cos(\theta *) & -\sin(\theta *) \\ \sin(\theta *) & \cos(\theta *) \end{bmatrix} \begin{bmatrix} Eqs \\ Eds \end{bmatrix} \quad (3)$$

Substituting (1) and (2) in (3) the voltage Eqe, Ede are given by (4)

$$\begin{bmatrix} Eqe \\ Ede \end{bmatrix} = E \begin{bmatrix} \cos(\theta * - \theta) \\ \sin(\theta * - \theta) \end{bmatrix} = \begin{bmatrix} \cos(\Delta\theta) \\ \sin(\Delta\theta) \end{bmatrix} \quad (4)$$

When $Ede = 0$,Phase Lock Loop is clamped. [3]

4.1.2 strategy of the current control

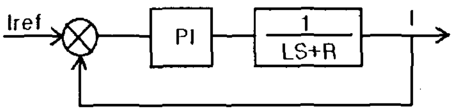

Fig 8. current control block

The output voltage and current equation.

$$Vs = Va + (L\frac{di}{dt} + R)i \quad (5)$$

The PI current controller

$$Va* = Vs - (Kp + \frac{Ki}{S})(i * - i) \quad (6)$$

The Va is eliminated using (1),(2), and the PI control transfer function is developed through (7),(8) [4,5,6]

$$(\frac{KpS + Ki}{S})i = (LS + R)i + (\frac{KpS + Ki}{S})i \quad (7)$$

$$\frac{i}{i*} = \frac{KpS + Ki}{LS^2 + (R + Kp)S + Ki} \quad (8)$$

4.2 PSC system simulation

The inverter control period is 100μsec and the voltage control period is 1000μsec which similar to DSP control periods. The H-Bridge inverter is used and uses the bipolar SPWM switching method.

The Constant MPPT algorithm is used in the simulation and P&O algorithm which has 50usec MPPT period is used in the experiment. The ripples generated from grid are eliminated by the digital low pass filter. It can be seen that phase locked current sinusoidal wave is synchronized with the grid voltage one in the simulation.

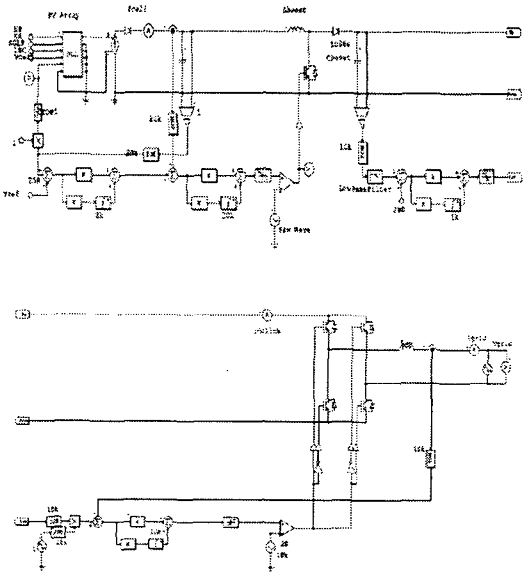

Fig 9. Simulation schematic of PCS

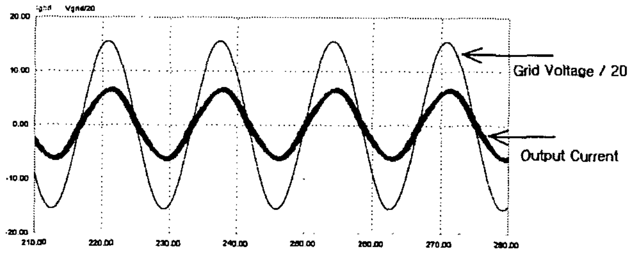

Fig 10. Output current & voltage waveforms

5. Experimental Result

The overall PCS system consists of 5 sensing parts, a control board (TMS320F240 DSP) and the IGBT gate drive.

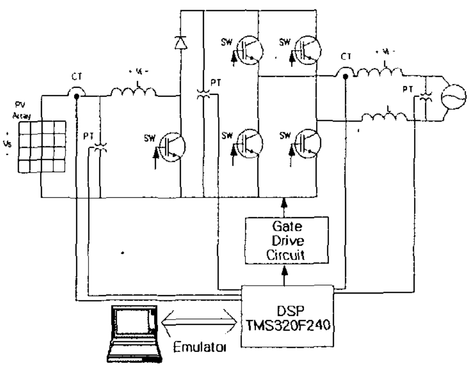

Fig 11. PCS experimental system

5.1 DC/DC converter experimental results

The PV array simulator is used in this experiment. The forth waveform is the DSP internal reference voltage. waveform and the third is the following real voltage one.

The second waveform is the DSP internal reference current made by the voltage controller and the first follows real current one. It is visible that real waveforms are following the reference one.

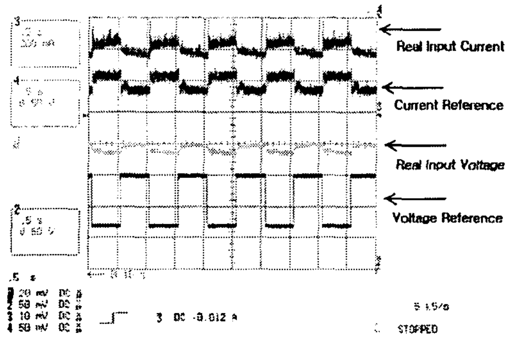

Fig 11. DC/DC converter control waveforms

The MPPT efficiency is above 99.5%.

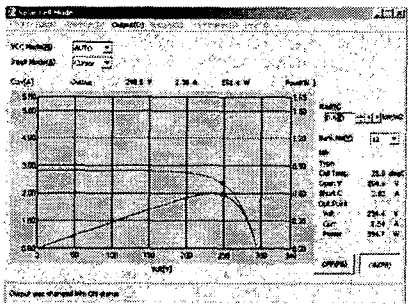

Fig 12. P&O MPPT plot in the 600 W/m^2

5.1 PCS system experimental results

The grid connected experiment was done with 110 [V] and 220 [V] utility voltages individually. The next figure is the wave of 220 [V] grid connected.

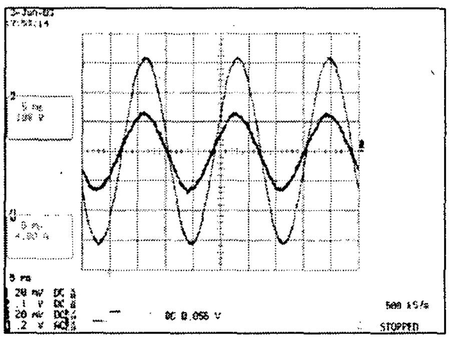

Fig 12. Phase voltage & current waveform of output

The following figure displays the efficiency and the current THD through the full load. The efficiency is approximately 94% and the current THD is approximately 5% through the full load.

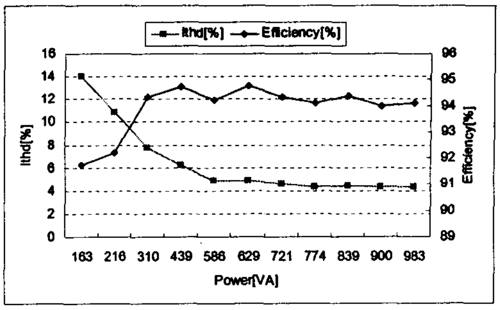

Fig 13. Efficiency & Current THD Curves

5. Conclusions

This paper describes the transformer-less type PCS which is more cost effective and physically smaller than transformer type PCSs. The proposed algorithm which selects DC/DC converter full digital control type MPPT is simpler and more efficient. The results are confirmed by simulations and experiments.

ACKNOWLEDGMENTS

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