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Implementation of a DC Power System with PVGrid- Connection and Active Power Filtering

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Abstract— The objective of this paper is to develop a DC power supply system with photovoltaic (PV) grid-connection and active power filtering. The proposed power supply system consists of an input stage and an output stage. In the input stage, a dc/dc converter incorporated with the perturbation-and-observation method can draw the maximum power from the PV source, which can be delivered to the output stage. On the other hand, grid connection or active power filtering, depending on the power of photovoltaic; will be implemented by a dc/ac inverter in the output stage. Two microcontrollers are adopted in the proposed system, of which one is to implement the MPPT algorithm, the other is used to determine the operation modes, which can be grid connection mode, direct supply mode or active power filtering mode. Finally, the experimental results are measured to verify the proposed algorithms and feasibility of the system.

Index Terms—About four key words or phrases in alphabetical order, separated by commas.

I. INTRODUCTION

Most of the traditional photovoltaic (PV) supply systems are composed of multi-stage converter [1]-[4]. The input-stage DC/DC converter is used to promote the input voltage and to draw the maximum power of solar energy source while the output-stage inverter is used to supply AC power to various AC loads. Such a system will cause much power dissipation due to multi-stage structure. In addition, when the illumination is insufficient during a cloudy day, rainy day or night, the PV supply system will suspend work. Thus, the overall utility of the PV supply system will greatly reduce.

For solving the above problems, a DC power system with PV grid-connection and active power filtering is proposed in this paper. In the proposed system, the output voltage of PV array is promoted only via single-stage DC/DC converter and supply directly DC power to the DC loads. Thus, the power dissipation which results from multi-stage converter will be improved. Besides, for promoting effectively the utility of PV supply system, the proposed system except fed the surplus PV power to the grid via DC/AC inverter [5], the grid can also supply insufficient power to the AC loads during illumination insufficient.

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In addition, the active power filtering function is designed and used to compensate the reactive power and eliminate the current harmonic for improving the power factor and power pollution of grid [6]-[7].Finally, the experimental results are presented to verify the proposed algorithms and feasibility of the system.

II. SYSTEM CONFIGURATION

A DC power system with PV grid-connection and active power filtering can be conceptually illustrated by Fig. 1, in which a schematic diagram of the proposed power system consists of PV array, DC/DC converter, full-bridge inverter, AC/DC rectifier, disconnection diode and two microcontrollers TMS 320LF2406A and PIC16F88. The TMS 320LF2406A is used to implement the DC/AC inverter control procedure and switching operational modes among the grid-connection mode, direct supply mode and active power filtering mode. The PIC16F88 is used to implement the control procedure of DC/DC converter and MPPT algorithm.

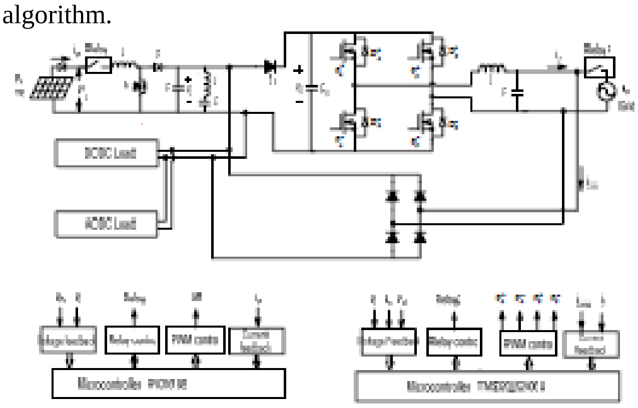

Fig. 1 Block diagram of the proposed DC power system

A. System Functions

As above illustration, the operational modes of the proposed system are divided into grid-connection mode, direct supply mode and active power filtering mode according to the output power of PV array. When external environment is under high illumination, the output power except support the DC load, the surplus power is fed to grid by DC/AC inverter. The power flow is shown as Fig. 2.

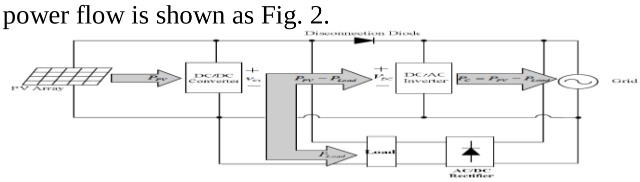

Fig. 2 The power flow of the system operates under the grid-connection mode

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When external environment is under middle illumination, the output power of PV array is approximate to the needed power of DC load, thus the system is operated in direct supply mode. Fig. 3 shows the power flow.

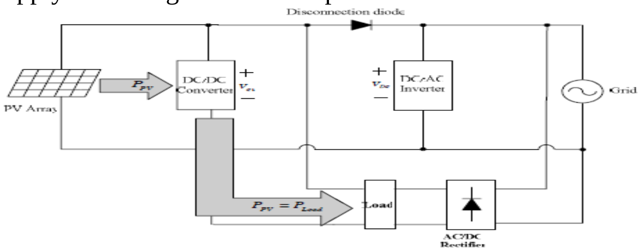

Fig. 3 The power flow of the system operates under the direct supply mode.

When external environment is under low illumination, the output power of PV array is not enough to support the DC load, the insufficient power of load will be compensated by grid via AC/DC rectifier. Thus the system is operated under the active power filtering mode. The power flow is shown as Fig. 4. By compensating the reactive power and distortion power by AC/DC rectifier, the power factor will be improved and harmonic will be eliminated in the system.

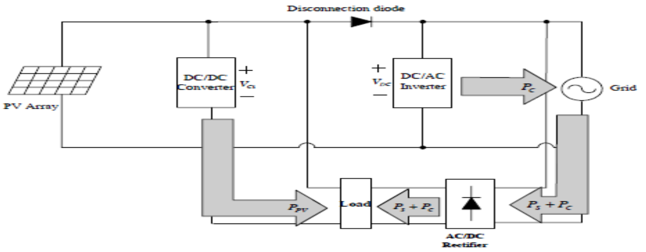

Fig. 4 The power flow of the system operates under active power filtering mode.

In Fig. 2, the disconnection-diode is used to automatic plug-in and disconnection control while the operational mode is changed between grid-connection mode and active power filtering mode.

B. DC/DC Boost Converter

A DC/DC boost converter is incorporated with the perturbation-and-observation method and used to promote the input voltage and to draw the maximum power of solar energy source in the proposed system. The boost converter, as shown in Fig. 5, contains power switch *S1*, power diode *D1*, inductor *L1*, input capacitor *C1* and output capacitor *C2* The relation of input voltage and output voltage is shown in equation (1), where *D*is turn on duty cycle of power switch.

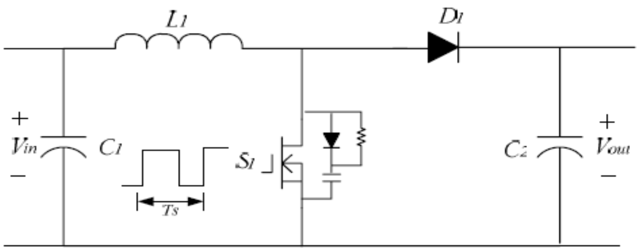

Fig. 5 DC/DC Boost converter

$$\frac{Vout}{Vin} = \frac{1}{1 - D} \qquad (1)$$

C. Full-Bridge Inverter

The output-stage inverter is composed of full-bridge power stage, DC-link capacitor and output filter, as shown in Fig. 6. The function of the full-bridge inverter is used to control the power switches to generate the modulation signal *vAB*. In general, there is much harmonic component in *vAB*, so a output filter is designed and used to filter the high frequency harmonic in *vAB*, thus, the 60Hz sinusoidal signal is achieved.

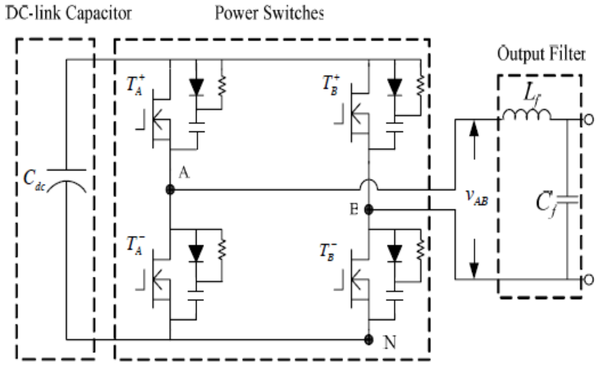

Fig. 6 The structure of Full-Bridge Inverter.

D. Design of output Filter

As illustrated above, output filter is used to filter the high frequency harmonic components in *vAB*. In the subsection, the output inductor and output capacitor will be designed.

Firstly, the resonant frequency is selected as equation (2), where *fo*is fundamental frequency and *fs*is system switching frequency.

$$10fo \le \frac{1}{2\pi\sqrt{LfCf}} \le \frac{fs}{10} \qquad (2)$$

Next, the output inductor is designed according to equation (3), where $VL(t) = Vdc - VS(t)$,$I_{lf}$is inductor ripple current and *T*sis switching cycle.

$$Lf \ge \frac{Vl(t)\times Ts}{2\Delta Ilf} \qquad (3)$$

The selection of output capacitor C f is dependent on maximum operating current and switching frequency. The maximum inductor ripple current is $0.25I_{Lf\text{-}peak}$ in a switching cycle, where $I_{Lf\text{-}peak}$ is peak inductor current. Thus, the minimum output capacitor is designed as follows:

$$Cf \ge \frac{Ts\times 0.25Ilf-peak}{2\Delta Vo}$$

III. SIMULATION RESULTS

(a) System specifications

Fig. 7 shows the sketch diagram of the proposed system structure, which contains two stages; the input stage is boost converter which is used to promote the input voltage and execute the maximum power point tracker of solar energy source. The output stage is full bridge inverter which is used to grid-connection and dynamically regulates the output power of solar energy in order to improving power quality. The system specifications are shown as follows:

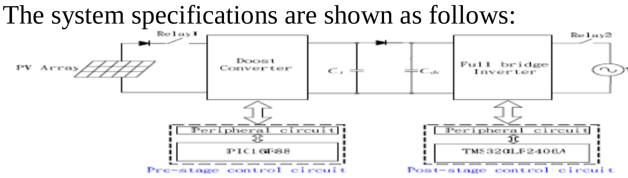

Fig. 7 The sketch diagram of system structure.

(i) Grid-connection mode electrical specification:

Mode judge voltage (VC1) > DC 400 V

DC_Bus voltage

(Vdc): DC 400V

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(ii) Active power filter mode electrical specification:
Mode judge voltage (VC1) < DC 311 V
DC_Bus voltage (Vdc): DC 450V

(iii) Direct supply mode electrical specification:
Mode judge voltage (VC1): DC 311 V~400 V

In this section, the experimental results of MPPT algorithm of DC/DC converter are firstly presented. The experimental results of grid-connection operational mode and active power filtering operational mode are next shown. Finally, the operation mode automatic-switching of the proposed system are verified.

(b) MPPT Function

The Observe and Perturb method (O & P method) is adopted to implement MPPT in this paper. Fig. 8 shows the conceptually testing circuit of MPPT algorithm. The specifications of DC/DC converter is shown as follows…

Input DC voltage: *Vd*= 250V, Input Maximum Current: *i1* = 4A, Switching Frequency: *fs*= 25kHz, Input Power: *Pin* = 500W, Input Series Resistor: *R1* = 25, Output parallel Resistor: *R2* = 200.

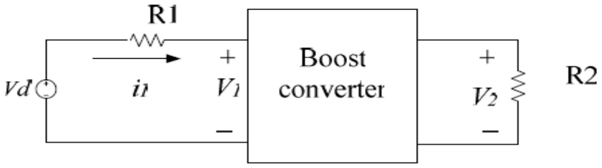

Fig. 8 The conceptual testing circuit of MPPT algorithm.

Fig. 9 shows the measured waveforms of MPPT algorithm of DC/DC converter. It can be seen that the maximum power point (MPP) of PV array can be obtained.

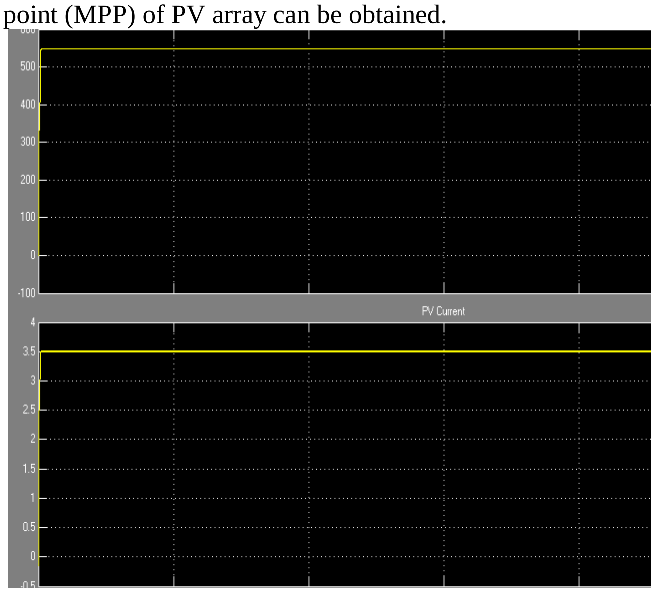

Fig. 9 **Voltage and current of photovoltaic system**

Fig. 10 Experimental results of the MPPT function of the boost converter operate under input voltage change (150V → 200V→150V).

(c) Grid-Connection Function

When system operates in the grid-connection mode, the DC/AC inverter is used to feed the PV power into grid and regulates power. Fig. 10 show the measured waveforms of AC voltage *Vac*and output current *ic*while output power is 1kW, 500W and 250W respectively. It can also be observed from these plots that the voltage and current is in phase, power factor > 0.99 and THD < 0.5

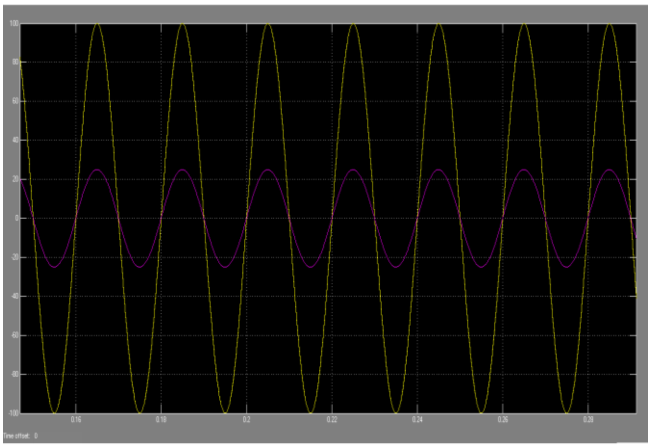

Fig. 10 The AC voltage *Vac*and output current *io*waveforms

(d) Active Power Filtering Function

When system operates under active power filtering mode, full-bridge inverter acts as a controllable current source which parallel with load and connect to the grid. Fig. 12 shows the sketch diagram of system which operates under active power filtering mode, by injection a compensated current iC to the power system, the grid current iS will in phase with grid voltage and achieve sinusoidal waveform. Thus, the current harmonic of power system will be reduced and power factor will be improved.

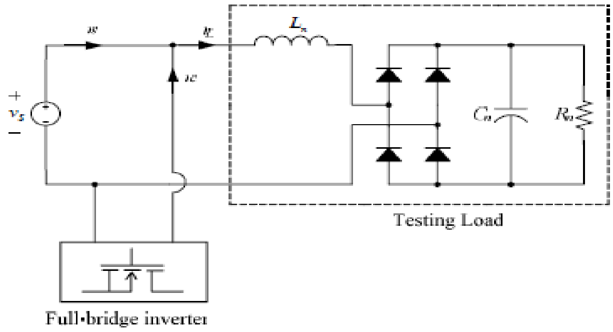

Fig. 11 The sketch diagram of system structure operates under active power filtering mode.

Table I. The testing values of relative parameter of grid with Rn=50Ω.

	W	VAR	VA	PF	V_{THD}	I_{THD}	A_{CF}
Before compensation	**1.25k**	**694**	**1.43k**	**0.87**	**2.8%**	**44.7%**	**1.858**
After compensation	**1.4k**	**200**	**1.42k**	**0.99**	**1.8%**	**8.4%**	**1.671**

Table I shows the testing values of relative parameter of grid before/after compensation with *Rn*=50Ω, It can be seen that the proposed system can effectively reduce the current THD and improve power factor. In addition, the parallel-type active power filtering is used in the system, thus all of the harmonics current, the grid voltage distortion which generated hi-order harmonic current and measured *VTHD* are reduced. Fig. 11shows the load current waveform with *Rn*=50Ω and table II presents the measured odd/even order harmonic amount of grid voltage and current.

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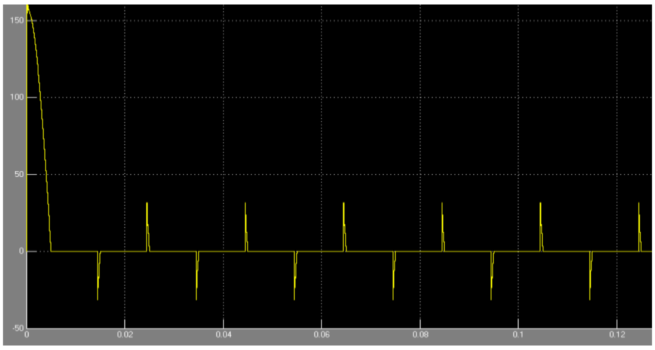

Fig. 12The load current waveform with *Rn*=50Ω.

Table II The measured odd/even order harmonic amount of grid voltage and current

	i_s		v_s	
	Before Compensation	After Compensation	Before Compensation	fter Compensation
Fundamental	6.114 A	6.323 A	215 V	215 V
2nd harmonic	0.044%	0.516%	0.02%	0.08%
3rd harmonic	44.36%	1.323%	0.323%	0.102%
4th harmonic	0.067%	0.12%	0.021%	0.038%
5th harmonic	3.752%	0.467%	1.014%	0.852%
6th harmonic	0.016%	0.152%	0.022%	0.043%
7th harmonic	3.768%	0.623%	0.873%	0.857%
8th harmonic	0.004%	0.268%	0.024%	0.012%
9th harmonic	2.878%	0.694%	0.072%	0.185%
10th harmonic	0.121%	0.132%	0.018%	0.023%
11th harmonic	2.867%	0.613%	0.351%	0.034%

standard IEC 1000-3-2 Class A beforeand after compensation, respectively. It can be seen thatthe 3rd harmonic is not match

with the harmonic standardof IEC_1000-3-2 in Fig. 11before compensation, but allof the harmonic component are match with theIEC_1000-3-2 in Fig. 14 after compensation.

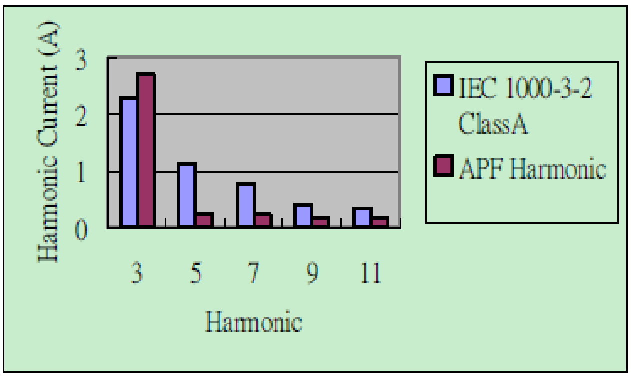

Fig. 13Comparison the measured harmonic amount ofgrid voltage and current with Europe harmonicstandard IEC 1000-3-2 ClassA before compensation

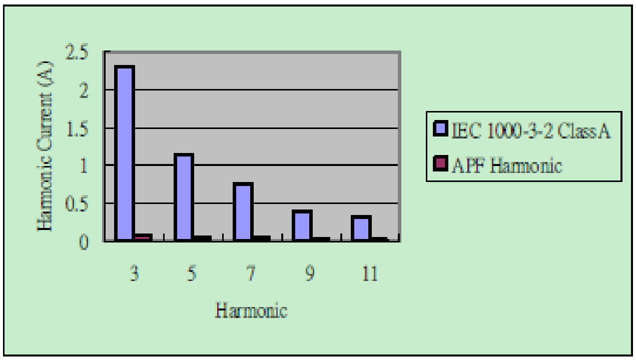

Fig. 14 Comparison the measured harmonic amount ofgrid voltage and current with Europe harmonicstandard IEC 1000-3-2 ClassA after compensation

The transient response of the proposed power systemwhich operates under load variation is shown as Fig. 16.It can be observed that the proposed system possessesvery well dynamic compensating features under activepower filtering mode no matter what the load vary fromheavy load to light load or from light load to heavy load.

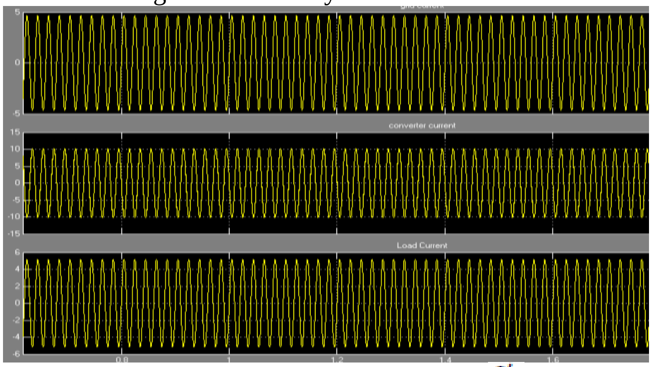

Fig. 15 Grid current *Ig*, converter current I'_C , and load current *I*load.

IV. CONCLUSIONS

A DC power system with PV grid-connection and active power filtering has been presented in this paper, in which a DC/DC converter is firstly used to promote the output voltage of PV array and achieve the MPP. The proposed system can automate switching among the grid connection mode, direct supply mode or active power filtering mode according to the output power of

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