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CURRENT TOTAL HARMONIC DISTORTION ANALYSIS OF PHOTOVOLTAIC POWERED SINGLE-PHASE INVERTER

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This paper is presented to analyze the current total harmonic distortion (CTHD) of photovoltaic (PV) powered single-phase inverter. The analysis is based on the performance of PV, battery and inverter a half day of different climate condition (clear and cloudy sky day). For a half day, solar irradiance, the voltage of PV and battery, CTHD of inverter are measured using solar power meter, electrocorder, and PM 300 power analyzer, respectively. The value of CTHD is analyzed and can be used to decide the electricity supply quality of the inverter.

Keywords: Solar irradiance; photovoltaic; inverter; current total harmonic distortion.

1. INTODUCTION

A photovoltaic can convert solar energy to direct current electrical energy. The major factors which influence the electrical design of the PV module are solar irradiance, tilt angle of PV module, load matching for maximum power and operating temperature [1]. The electrical characteristics of PV module are dependent on solar irradiance and temperature. If the solar irradiance is constant and although the temperature increase will cause the short circuit current still constant, if the solar irradiance is constant and the temperature increase will cause the open circuit voltage, maximum power and efficiency decrease, if the temperature constant and solar irradiance increase will cause the short circuit current, open circuit voltage, maximum power and efficiency increase [2],[3].The tilt angles of PV module effect on the solar irradiance that fall on its surface. The tilt angles of PV module in Perlis, Malaysia are -17.16^0 to 29.74^0. The positive, zero and negative tilt angles indicate that the PV module is inclined to face south, on horizontal surface and north, respectively [4].

The direct current (DC) electrical energy of PV module can be converted to alternating current (AC) electrical energy using inverter. The 1.5 kW inverter using full bridge topology is designed and tested by [5]. It gave an excellent result for the high power PV module application. An alternative approach of inverter is proposed by [6] to replace the conventional method with the use of microcontroller. The use of the microcontroller brings the flexibility to change the real-time control algorithms without further changes in hardware. It is also low cost and has small size of control circuit for the single phase full bridge inverter.

In grid or off grid connected installation, the inverter input power is determined by the solar irradiance on the PV module, that is, both the efficiency and the electricity supply quality depend on the inverter work point (obviously this depends on the solar irradiance incident on the surface of the PV module) [7]. A method to study the electricity supply quality is to use the current total harmonic distortion. A simulation program has been developed to simulate the harmonic current emission of PV system under different solar radiation conditions [8]. The simulation is based on measured data of temperature and global solar radiation. The result indicated an excellent correspondence between simulation and measurement result.

This paper presents the CTHD analysis of PV powered single phase inverter that is related on the measured data of solar irradiance. The analysis is based on the performance of PV, battery and inverter a half day of different climate condition (clear and cloudy sky day). For a half day, solar irradiance, the voltage of PV and battery, CTHD of inverter are measured using solar power meter, electrocorder, and PM 300 power analyzer, respectively.

2. METHODOLOGY AND DATA

2.1 Electricity supply quality of an inverter

As stated above, the electricity supply quality of an inverter can be studied from the CTHD. The waveform of an inverter sine wave can be obtained from the well-known expression [7]:

$$f(t) = A \sin \omega t \tag{1}$$

where A is the amplitude, ω is angular velocity in rad/s and t is time in second. When the waveform is deformed with respect to the previous expression, it is said that the waveform has a harmonic perturbation. The harmonic spectrum is the decomposition of a signal in its harmonics. These are sine wave oscillations in frequencies that multiplied from the fundamental frequency. The total harmonic distortion is defined with respect to the fundamental component and calculated by the expression

$$THD = \frac{\sqrt{(h_2)^2 + (h_3)^2 + ... + (h_n)^2}}{h_1} x100\% \qquad (2)$$

where h_1, h_2, h_3..., h_n represent the effective value of the harmonics for orders 1,2,3,…,n. Obviously, if the wave is an ideal sine wave, the total harmonic distortion is zero.

2.2 Data of inverter

A FSNW0.8KD hybrid of inverter and controller is used in this experiment. It adopts dedicated microcomputer chip and non-contact control technology, and has protection system. The main electric circuit adopts USA FC MOSFET and the most advanced intelligent power module IGBT, having good transient response, and high efficiency in inverting. The technical parameters of the inverter are shown in Table 1.

Table 1. The technical parameters of FSNW0.8KD hybrid of inverter and controller

Type		FSNW0.8KD
DC input	Rated capacity (kW)	0.8
	Input rated voltage (V)	24
	Input voltage recommended range (V)	22 ~ 33
AC output	Rated capacity (kW)	0.7
	Rated voltage (V)	230 true sinewave
	Rated frequency (Hz)	50
	Over load ability	120% 1 minute
	Frequency steady precision (Hz)	50 ± 0.04
	Total harmonic distortion (THD)	≤ 3% (linear load)
	Dynamic response (0~100%)	5%
	Voltage steady precision (V)	230 ± 3%
	Inverter efficiency (80% load)	85%

2.3 Experiment setup

The main equipments consist of PV module, FSNW0.8KD hybrid of inverter and controller, battery, AC loads, and the measurement equipments consist of solar power meter, electrocorder, and PM 300 power analyzer. These equipments block diagram is shown in Fig. 1.

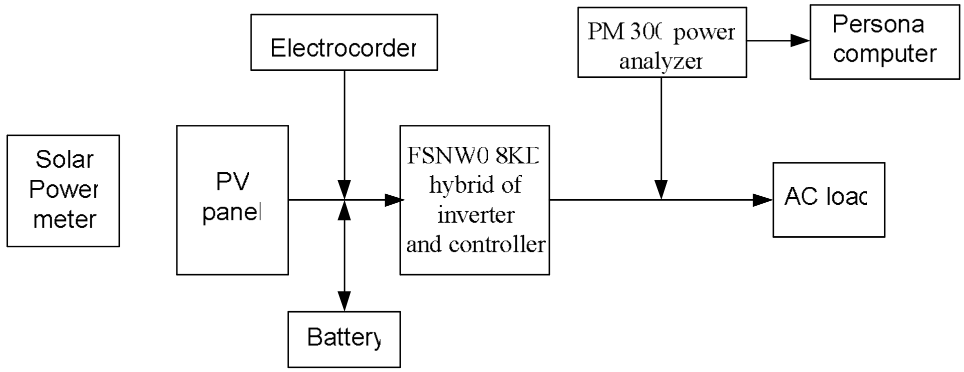

Fig. 1. Equipments block diagram

The solar power meter is used to measure the solar irradiance that incident on the surface of PV module. The solar power meter is set using solar meter software, therefore it can record the solar irradiance every minute, and the recorded solar irradiance can be downloaded using the software.

Four units of Uni-Solar PV module are used to generate DC electrical energy. Each PV module has rated maximum power of 62 W, maximum current of 4.13 A and maximum voltage of 15 V. Each two units of the PV module are connected in series and connected in parallel each other to be a PV panel. The PV panel has rated maximum power of 248 W, maximum current of 8.26 A and maximum voltage of 30 V. The PV panel is used to charge the 24 V battery and run the inverter. The AC voltage of the inverter is used to serve the AC load.

The electrocorder is used to measure the voltage of PV panel, the voltage and current of battery. The electrocorder is set using electrosoft software, therefore it can record the voltage and current every minute, and the recorded value can be downloaded using the software.

The PM 300 power analyzer is used to measure the AC load average power, power factor and the CTHD. It is set using VPAS lite software, therefore the measurement can be recorded every minute and downloaded by the software.

3. RESULT AND DISCUSSION

The CTHD analysis of PV powered single-phase inverter is done a half day of different climate condition (clear sky day on 20 August 2010 and cloudy sky day on 21 August 2010). The measurement of the solar irradiance, the voltage of PV and battery, CTHD of inverter are done from 8.37 am to 12.00 am.

3.1 Solar irradiance, PV voltage, battery voltage and current

The solar irradiance, PV and battery voltage on the clear and cloudy sky day are shown in Fig. 2, 3, and 4, respectively.

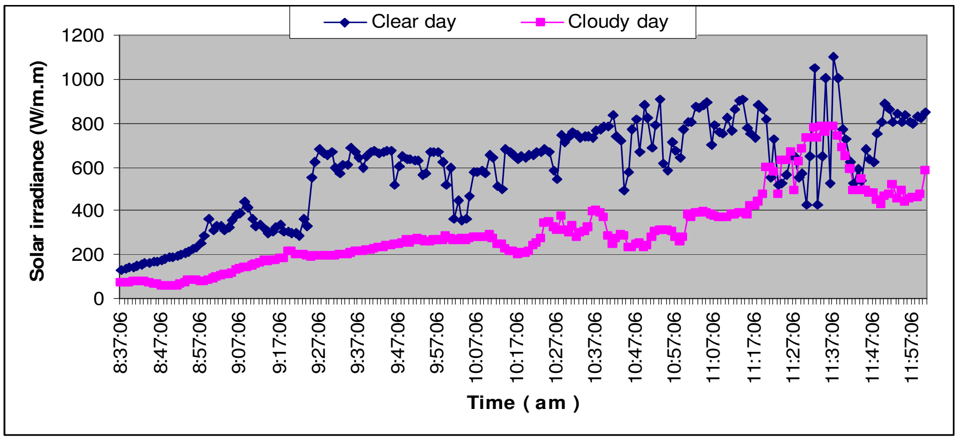

Fig. 2. Solar irradiance on clear and cloudy sky day

Fig. 2 shows that on the clear sky day the solar irradiance is higher than on the cloudy sky day. On the clear sky day, the minimum, maximum and average solar irradiance are 130.6 W/m^2, 1102 W/m^2, and 589 W/m^2, respectively. On the cloudy sky day, the minimum, maximum and average solar irradiance are 55.5 W/m^2, 786 W/m^2, and 304 W/m^2, respectively. The maximum solar irradiance on the clear and cloudy sky day happen on the same time, exactly on 11.37 am. If the average solar irradiance is referred, the clear percentage on the clear sky day is higher of 48.4 % than the cloudy sky day.

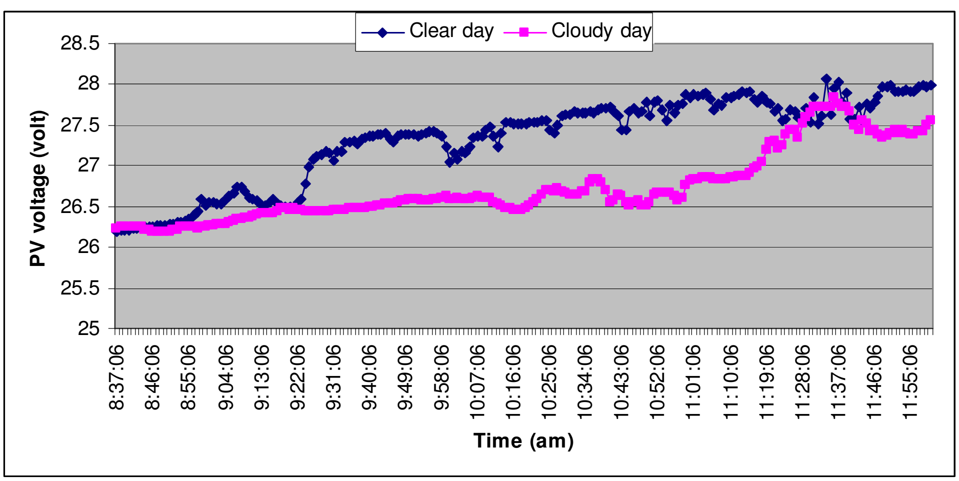

Fig. 3. PV voltage on clear and cloudy sky day

Fig. 3 shows the PV voltage on the clear and cloudy sky day. If it is related to solar irradiance in Fig. 2, it can be stated that the PV voltage is proportional to the solar irradiance. It is also according to what stated by [2],[3] (if the temperature constant and solar irradiance increase will cause the PV module voltage will increase). On the clear sky day, the minimum, maximum and average PV panel voltage are 26.2 V, 28.02 V, and 27.32 V, respectively. On the cloudy sky day, the minimum, maximum and average PV panel voltage are 26.19 V, 27.83 V, and 26.73 V, respectively.

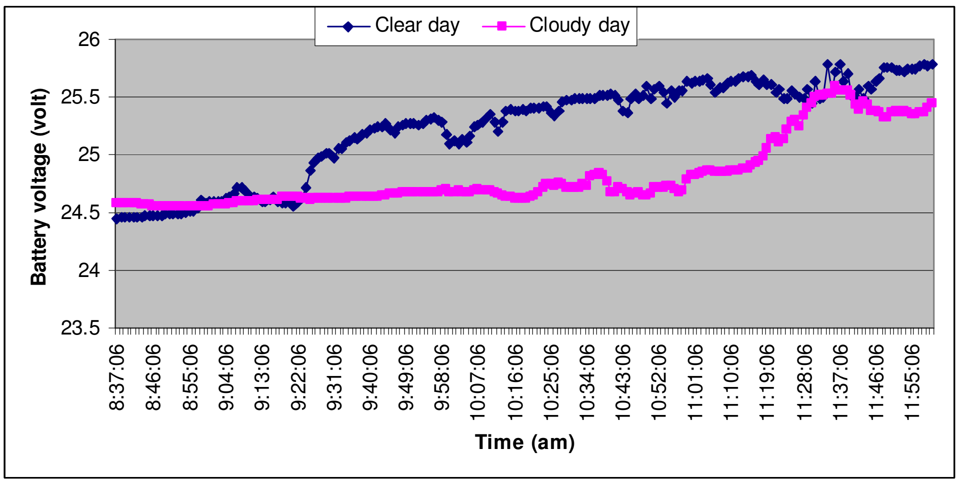

Fig. 4. Battery voltage on the clear and cloudy sky day

On 8.37 am, the starting voltage of battery on the cloudy sky day is higher then on the clear sky day, but because the solar irradiance on the clear sky day is higher then on the cloudy sky day, the battery voltage on the clear sky day will increase and on the cloudy day will decrease, as shown in Fig. 4. It indicates that the battery voltage is proportional to the solar irradiance. On the clear sky day, the minimum, maximum and average battery voltage are 24.45 V, 25.79 V, and 25.23 V, respectively. On the cloudy sky day, the minimum, maximum and average battery voltage are 24.55 V, 25.60 V, and 24.82 V, respectively.

3.2 Current total harmonic distortion

The AC loads of the inverter are DC power supply, PM 300 analyzer and 12 V DC adaptor. They are nonlinear loads that have rich harmonics. The voltage and current waveform of the loads are shown in Fig. 5.

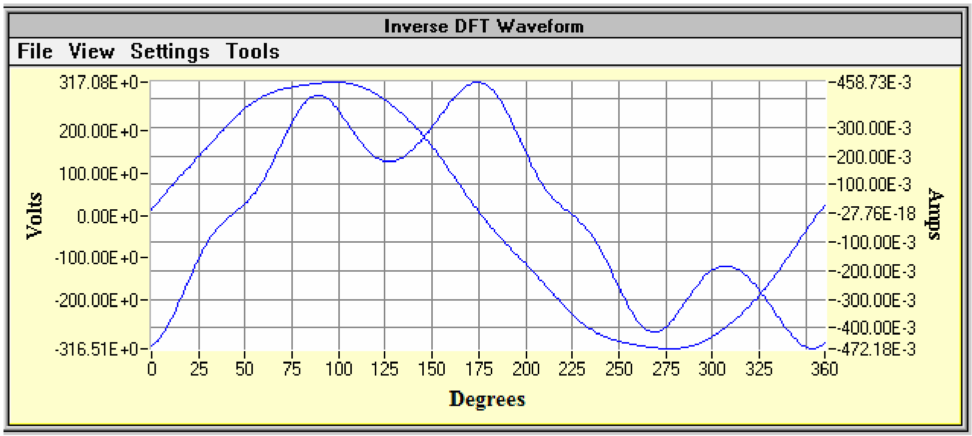

Fig. 5. Voltage and current waveform of loads

Fig. 5 shows that the loads voltage waveform is true sine wave that has rms value of 220.8 V, but the loads current waveform is not true sine wave and has rms value 0.298 A. The loads current waveform has rich harmonics and its harmonic spectrum is shown in Fig. 6. The 1st, 3rd, and 5th current harmonic spectrum are 0.273 A, 0.101 A, and 0.051, respectively.

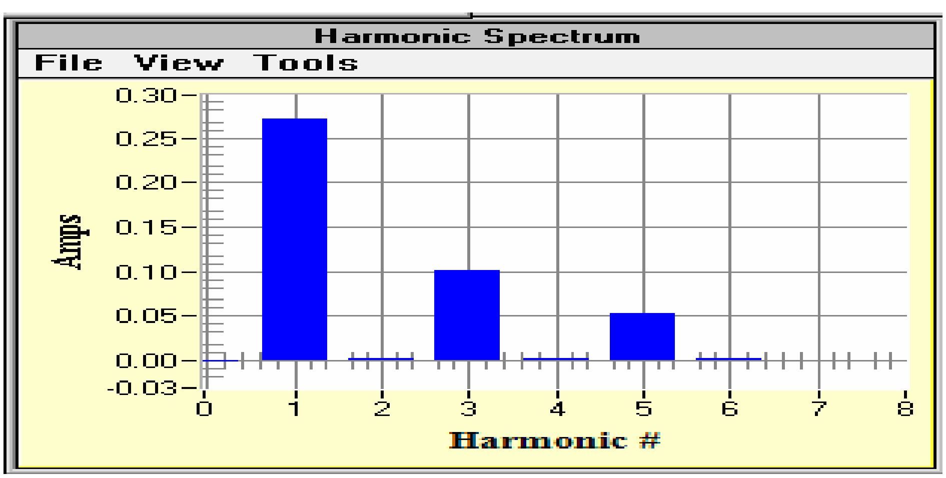

Fig. 6. Current harmonic spectrum

The CTHD is measured every minute and related to the solar irradiance as shown in Fig. 7.

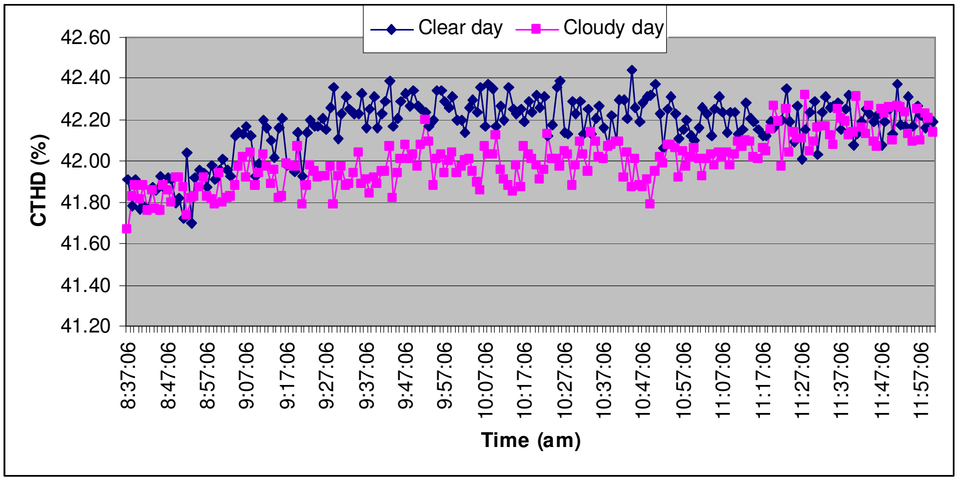

Fig. 7. Current total harmonic distortion

The solar irradiance on the clear sky day is higher than on the cloudy sky day as shown in Fig. 2. If the solar irradiance is related to the CTHD as shown in Fig. 7, it indicates that the CTHD is proportional to the solar irradiance. If the solar irradiance increase, the CTHD will increase. On the clear sky day, the minimum, maximum and average CTHD are 41.70 %, 42.44 %, and 42.17 %, respectively. On the cloudy sky day, the minimum, maximum and average CTHD are 41.67 %, 42.32 %, and 42 %, respectively.

4. CONCLUSION

Voltage of PV panel and battery are proportional to the solar irradiance, if the solar irradiance increase the voltage will increase. On the clear sky day, the solar irradiance, voltage of PV panel and battery are higher than on the cloudy sky day.

Based on the data sheet and experiment of the FSNW0.8KD hybrid of inverter and controller, it is a good supply quality of an inverter because it has total harmonic distortion below 3% for linear load. When the inverter serves the nonlinear load, the CTHD increases and its value depends on the solar irradiance, if the solar irradiance increases, the CTHD will increase.

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References

[1] Cook, G.; Billman, L.; and Adcock, R. (1995). *Photovoltaic Fundamental*. DOE/Solar Energy Research Institute Report No. DE910115001.

[2] Irwanto, M.; Daut, I.; Sembiring, M.; Ali, R.; Champakeow, S.; and Shema,S. (2010). Effect of Solar Irradiance and Temperature on Photovoltaic Module Electrical Characteristics. *International Postgraduate Conference on Engineering (IPCE 2010).*

[3] Irwanto, M.; Daut, I.; Sembiring, M.; Ali, R.; Hardi, S.; and Maizana, D. (2010). Optimazation of Photovoltaic Module Electrical Characteristics Using Genetic Algorithm. *International Postgraduate Conference on Engineering (IPCE 2010).*

[4] Daut, I.; Irwanto, M. (2010). Optimal Tilt Angle of Photovoltaic Module in Perlis, Malaysia. *International University Social Responsibility Conference and Exhibition 2010 (IUSRCE2010).*

[5] Taib, S.; Sutanto, Y.; and Razak, A. R. A.(2002). Development of Simple PWM Inverter Using Photovoltaic Celss. *2002 Student Conference on Research and Development Proceeding.*

[6] Ismail, B.; Toib, S.; Saad, A. R. M.; Isa, M.; and Hadzar, C. M. (2006). Development of a Single Phase SPWM Microcontroller-Based Inverter. *First International Power and Energy Conference PECon 2006.*

[7] Cardona, M. S.; Carretero, J. (2005). Analysis of the Current Total Harmonic Distortion for Different Single-Phase Inverters for Grid-Connected PV Systems. *Science Direct, Solar Energy Materials & Solar Cells 87 : 529-540.*

[8] Schlabbach, J.; Kammer, L. (2006). Prediction of Harmonic currents of PV-Inverter Using Measured Solar Radiation Data.