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### Comparative Study on AC Square and Three-Level Wave Form of Photovoltaic and Wind Power Hybrid Single Phase Inverter

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#### Abstract

This paper presents a new topology of three-level single phase photovoltaic (PV) and wind power hybrid inverter. It consists of four main circuits; they are a hybrid controller circuit, a charger circuit, a pulse driver and full bridge circuit. The inverter is installed in front of Electrical Energy and Industrial Electronic Systems (EEIES) Cluster, Universiti Malaysia Perlis, Northern Malaysia. Objective of this paper is to compare current total harmonic distortion (CTHD) of the alternating current (AC) square and three-level wave of PV and wind power hybrid single phase inverter. In this research, the AC waveforms are developed and created by a microcontroller PIC16F627A-I/P. The result shows that for a load of 20 W AC water pump, the AC waveforms effect on the CTHD. The CTHD is lower when the PV and wind power hybrid single phase inverter is formed as AC three-level wave than as AC square wave. Average CTHD of the square wave is 19.84% and average CTHD of the three-level waveform is 7.56%. Hence the improvement in the average CTHD obtained when a three-level wave of the PV and wind power hybrid single phase inverter is used will be about 62% if compared with the square wave. It indicates that the PV and wind power hybrid single phase inverter formed as AC three-level wave is better than as AC square wave.

**Keywords:** AC wave form, photovoltaic, wind power, inverter, current total harmonic distortion (CTHD)

#### Introduction

Direct current (DC) electrical energy of PV module can be converted to AC electrical energy using inverter. 1.5 kW inverter using full bridge topology is designed and tested by Taib.S et. al [1]. It gave an excellent result for the high power PV module application. An alternative approach of inverter is proposed by Ismail. B et. al [2] to replace the conventional method with the use of microcontroller. 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) Cardona M. S et. al [3].

This paper presents a new topology of three-level single phase PV and wind power hybrid inverter. It consists of three main circuits; they are a hybrid controller circuit, a charger circuit and a pulse

driver and full bridge circuit. The advantage of the proposed topology compared to the conventional inverter is that the pulse waves to drive the full bridge inverter circuit is easy to create using the microcontroller PIC16F627A-I/P. The pulse waves effect on maximum voltage angle of the AC waveform and the CTHD. Using the microcontroller, an optimum value of the maximum voltage angle can be obtained to reduce the less CTHD.

#### Methodology

##### PV and wind power hybrid generation

The PV and wind power hybrid single phase inverter, and a Vantage Weather Station Pro2 are installed in front of EEIES Cluster, Universiti Malaysia Perlis, Northern Malaysia as shown in Fig. 1. The inverter main energy source consists of two parts, the first is a PV array that consists of two unit PV modules, each unit has capacity of 22 V, 50 W and the second is a wind power generation as shown in Fig. 1. In this research, the data of solar irradiance, wind speed, PV voltage and wind power generation voltage are measured every minute on the same time from 24<sup>th</sup> to 25<sup>th</sup> March 2014. This objective is to

relate between the solar irradiance, wind speed and PV, wind power generation performance. The solar irradiance and wind speed are measured by the Vantage Weather Station Pro2, the PV voltage and wind power generation voltages are measured by a voltage logger.



(a) Weather station



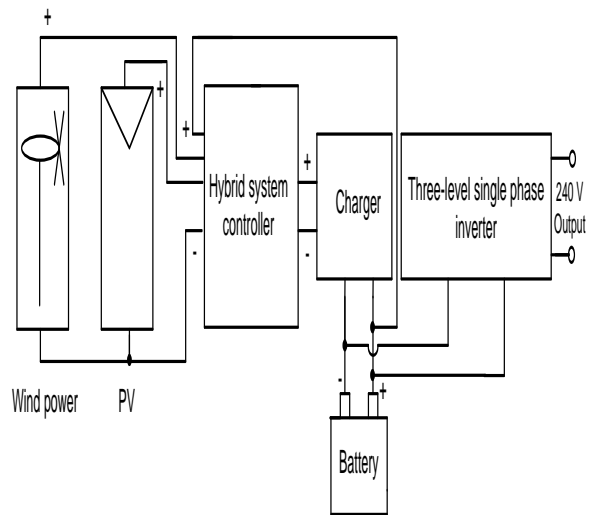
(b) PV array and wind power generation

**Fig. 1** Weather station, PV array and wind power generation are installed in front of EEIES Cluster, Universiti Malaysia Perlis

**Proposed topology of the three-level single phase PV and wind power hybrid inverter**

The realized system is a three-level single phase PV and wind power hybrid inverter that can

feed AC loads. The complete system is shown in Fig.2 that consists of three main circuits; they are a hybrid system controller, a charger and a three-level single phase inverter circuit.



**Fig. 2** Realized three-level single phase PV and wind power hybrid inverter system

The hybrid system controller is used to control input of the PV and wind power generation voltage to the charger. Its circuit is shown in Fig. 3. During the night time, the PV array can not produce DC voltage, but during the day time produces DC voltage. Value of the voltage is depend on the solar irradiance. The wind power generation can produce DC voltage during the night and day time. Value of the voltage is depend on the wind speed.

The hybrid system controller is designed to control the battery charger. It operates if the PV array voltage or wind power generation voltage is higher than the battery voltage or PV array and wind power generation voltage are higher than the battery voltage. This system is controlled by the microcontroller PIC16F677A.

Fig. 4 shows a charger circuit used to charge the battery. The 15 V to 40 V DC voltages are sent to input of the charger circuit. The diode  $D_3$  is used as a crowbar device, if reverse power is applied to the circuit, the diode causes a short circuit and the 4 Amp fuse blows. The input voltage is stabilized with the capacitor  $C_5$ . This is also used as a local power reservoir for the switching regulator. The optional 1 k $\Omega$  green LED in series with the 1 k $\Omega$  resistor provides an indication that the circuit is powered.

The LM2576-ADJ voltage regulator provides variable width DC pulses to the inductor  $L_1$ . When the output pulse is on, the inductor stores energy. When the pulse turns off, the inductor discharges energy into the capacitor  $C_6$  through the current loop with the schottky diode  $D_4$ . The resistor  $R_5$  and trimmer potentiometer  $R_6$  form a voltage divider circuit. This is used as feedback by the LM2576-ADJ IC for setting the output voltage.

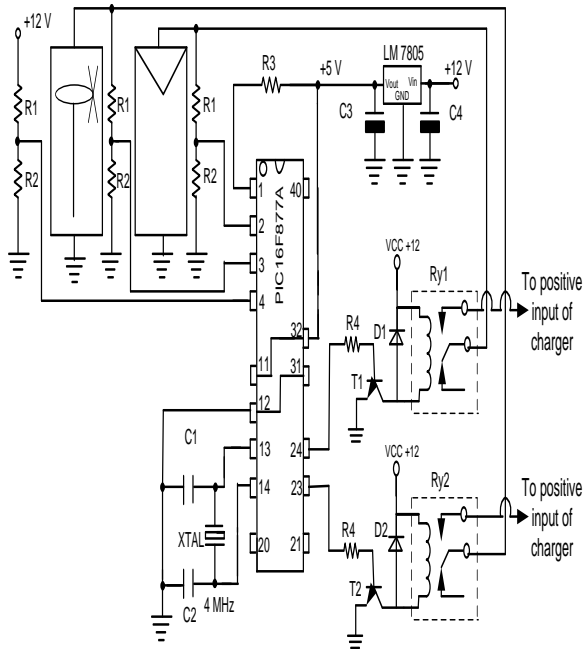


Fig. 3 Hybrid system controller circuit

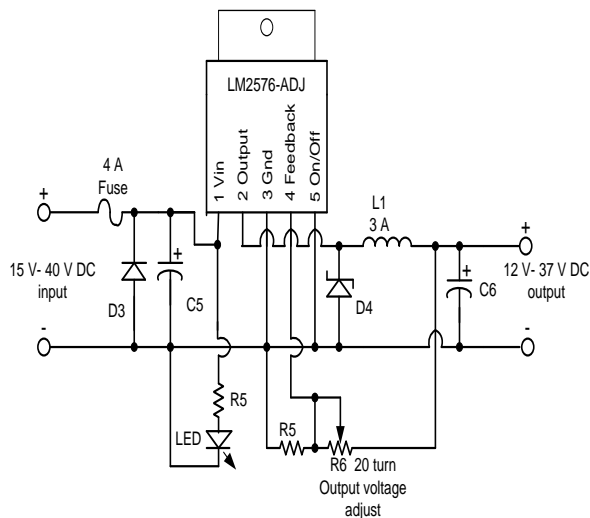


Fig. 4 Charger circuit

Fig. 5 shows a full bridge inverter circuit that is driven by five pulse waves and created by the microcontroller PIC16F627A-I/P at pin 10, 11, 12, 17 and 18.

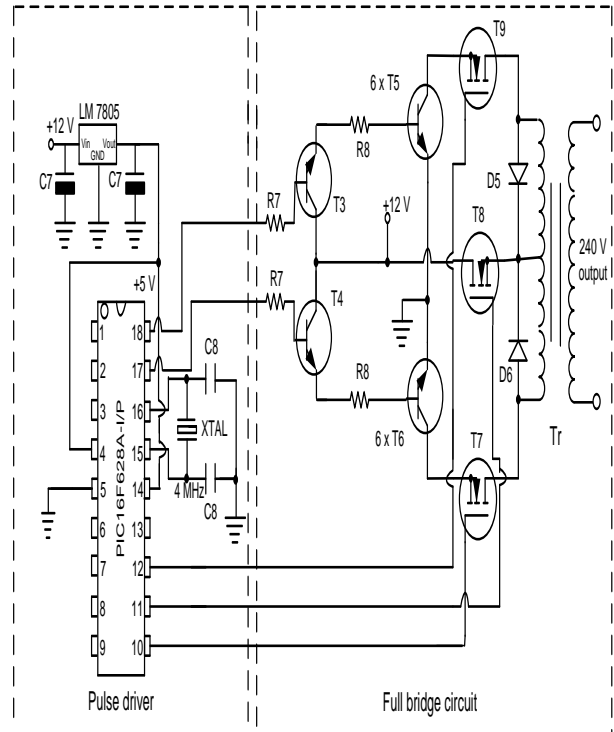


Fig. 5 Three-level single phase inverter circuit

### Experimental set up

Experimental set up equipments of the PV and wind power hybrid single phase inverter consist of PV array, hybrid controller circuit, charger circuit, pulse driver circuit, full bridge circuit, battery, and a load of 20 W 220 V 50 Hz AC water pump. Measurement equipments consist of Vantage Weather Station Pro2, electrocorder voltage logger, and PM 300 Analyzer. The experiment setup is shown in Fig. 6.

As shown in Fig. 6, input of the three-level single phase PV and wind power hybrid inverter is connected to the PV array and wind power, its output is connected to the load of 20 W 220 V 50 Hz AC water pump. The PV array and wind power output voltage are measured by electrocorder voltage logger which their value depend on solar radiation, temperature and wind speed. The solar radiation, temperature and wind speed are measured by the Vantage Weather Station Pro2. Performances of the

load are measured by the PM 300 Analyzer. The measurements are real time system and recorded every minute through 24<sup>th</sup> to 25<sup>th</sup> March 2014.

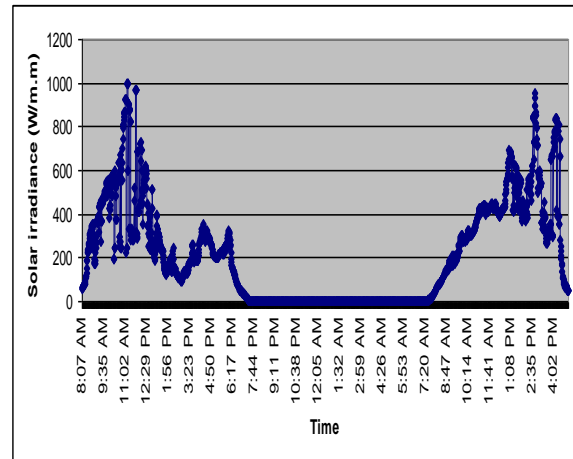


Fig. 6 Experimental set up

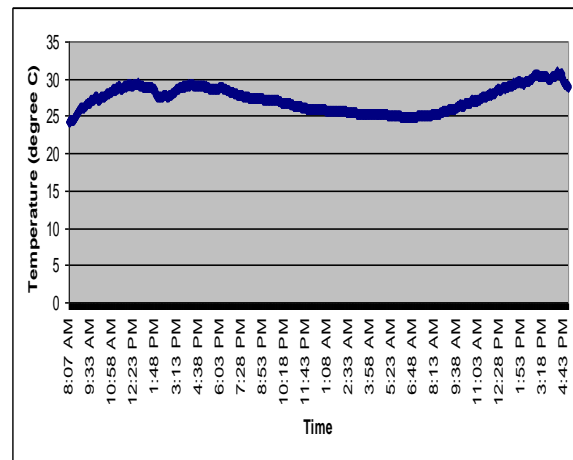
### Result and discussion

#### Weather condition, PV array and wind power generation voltage

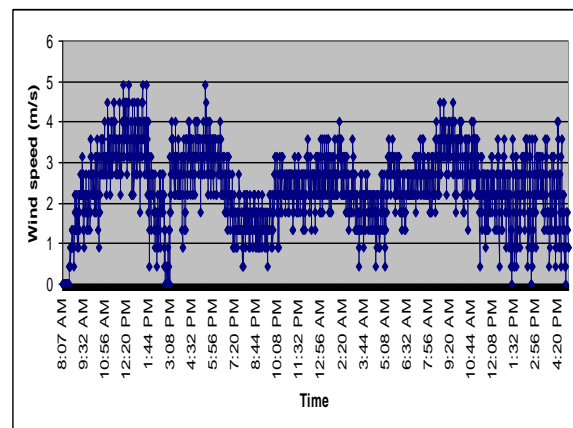
Fig. 7 shows measurement of the solar radiation, temperature and wind speed on 24<sup>th</sup> to 25<sup>th</sup> March 2014. Minimum, maximum and average of the solar irradiance are 0 W/m<sup>2</sup>, 997 W/m<sup>2</sup>, and 207.3 W/m<sup>2</sup>, respectively. Minimum, maximum and average of the temperature are 24.3 °C, 30.9 °C and 27.34 °C, respectively. Minimum, maximum and average of the wind speed are 0 m/s, 4.92 m/s and 2.39 m/s, respectively.



(a) Solar irradiance



(b) Temperature



(c) Wind speed

Fig. 7 Weather condition

The solar irradiance and temperature effect on the PV array output voltage, and wind speed effects on the wind power generation voltage. If the solar irradiance increase and assuming the temperature is constant cause the PV array output voltage increase, otherwise if the temperature increase and assuming the solar irradiance is constant cause the PV array output voltage decrease, Irwanto. M at. al, Daut. I. et. al [4, 5, 6]. If the wind speed is lower than cut-in speed and highest than cut-off speed, thus the wind power generation voltage is zero, if the wind speed is higher than the nominal speed and lowest the cut-off speed, thus the wind power generation voltage is its rated voltage, Daut. I et. al [7]. The PV array and wind power generation output voltage on 24<sup>th</sup> to 25<sup>th</sup> March 2014 are shown in Fig. 8.

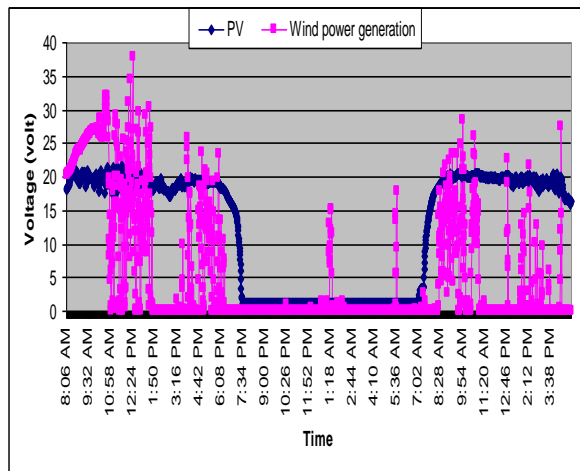


Fig. 8 PV array wind power generation output voltage

**Voltage waveform of square and three-level single phase PV and wind power hybrid inverter**

The full bridge inverter circuit is driven by the pulse waves that created by the pulse driver circuit, exactly by the microcontroller PIC16F627A-I/P as shown in Fig. 5. If the outputs of the pulse driver circuit at pin 10, 11, 12, 17 and 18 are pulse waves as shown in Figs. 9 and 10, therefore secondary side voltage waveform of the transformer are AC square wave and three-level waveform as shown in Figs. 11(a) and (b), respectively . The load of 20 W 220 V 50 Hz AC water pump is connected to secondary side of the transformer which is inductive load therefore the load voltage leads its current by 53.13° as shown in Fig. 11.

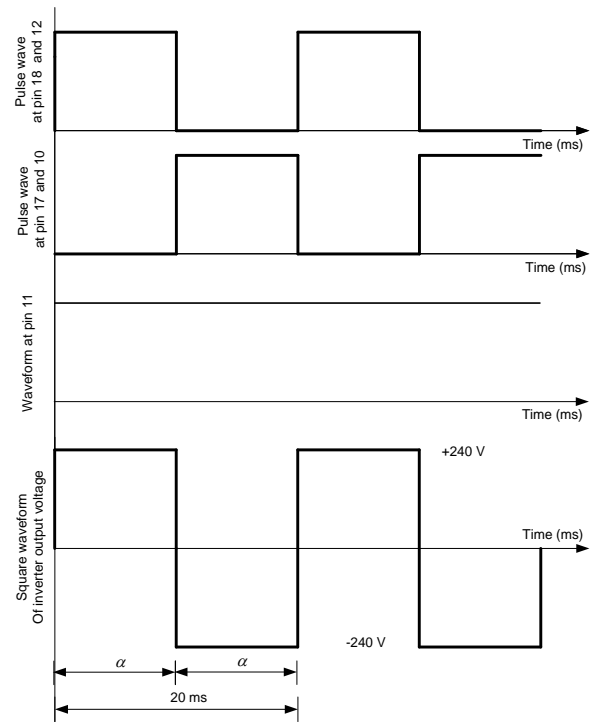


Fig. 9 Pulse and square wave of the PV and wind power hybrid single phase inverter

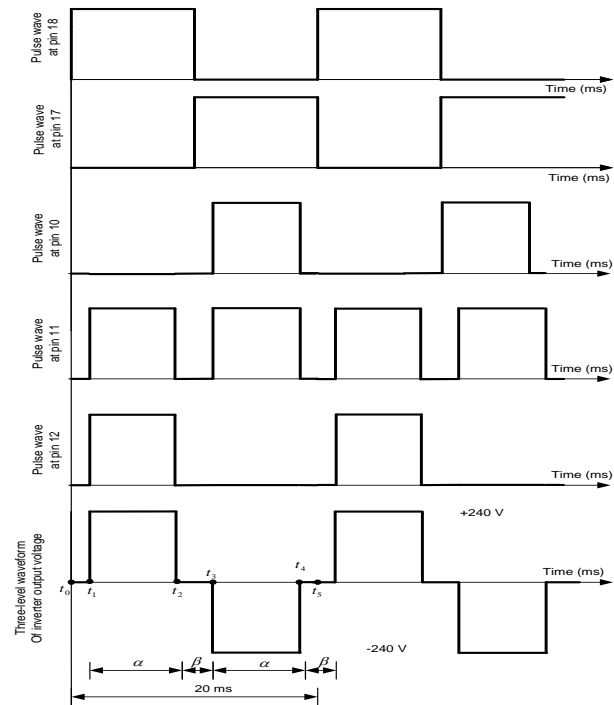
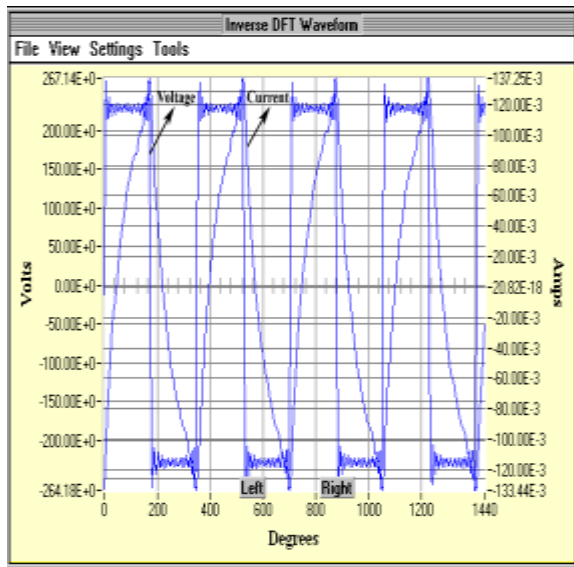
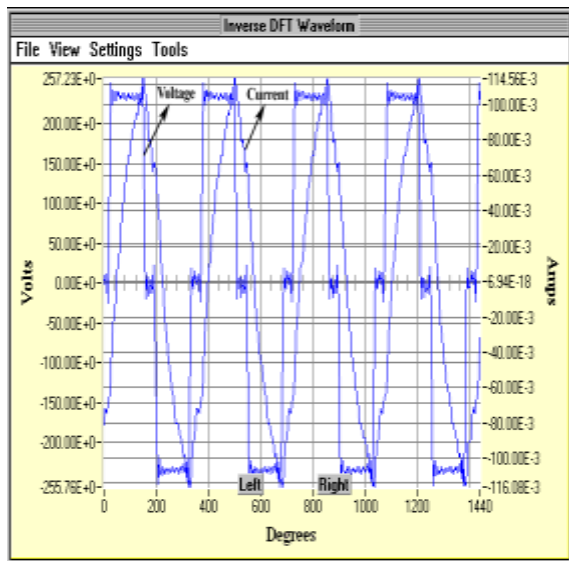


Fig. 10 Pulse and three-level wave of the PV and wind power hybrid single phase inverter





(a) Square wave



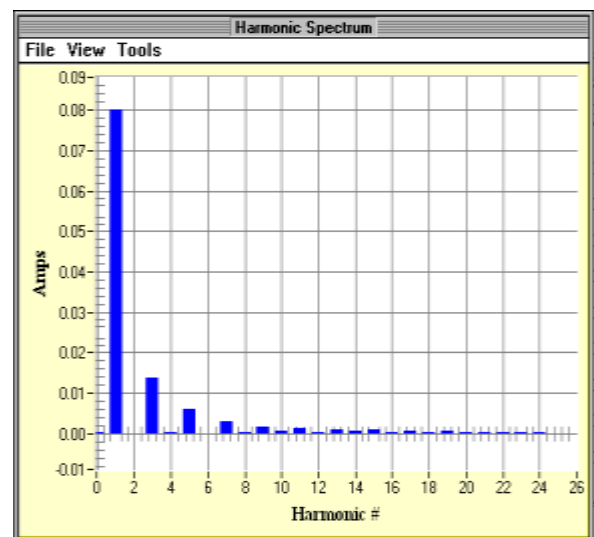
(b) Three-level waveform

Fig. 11 AC load voltage and current waveform of the PV and wind power hybrid single phase inverter

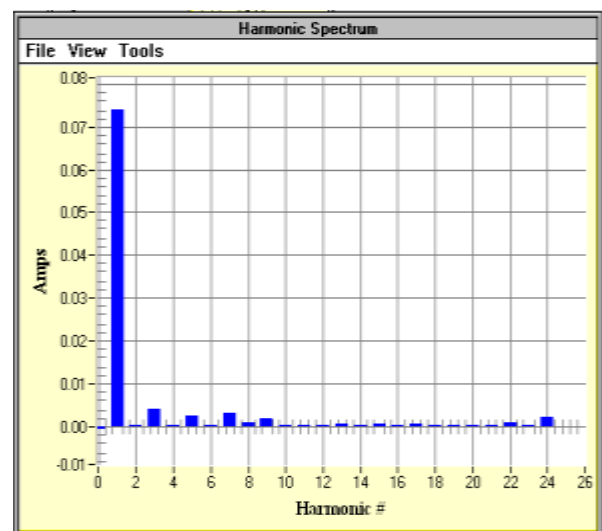
Fig. 11 shows that AC load rms voltage and current are higher when the PV and wind power hybrid single phase inverter is formed as AC square wave than as AC three-level waveform. It means the AC waveform which is formed by the PV and wind power hybrid inverter effects on AC load rms voltage and current.

### Current total harmonic distortion (CTHD)

The load of 20 W 220 V 50 Hz AC water pump which is connected to secondary side of the transformer will produce CTHD and depends on type of AC waveform. Current harmonic spectrums of square and three-level single phase PV and wind power hybrid inverter are shown in Fig. 12. The current harmonic spectrum is lower when the single phase PV and wind power inverter is formed as AC three-level waveform than as AC square wave. It indicates that the single phase PV and wind power hybrid inverter is formed as AC three-level waveform is better than as AC square wave.



(a) Square wave



(b) Three-level waveform

Fig. 12 Current harmonic spectrum of the single phase PV and wind power hybrid inverter

From Fig. 12 can be concluded that in the case of square wave (where  $\delta = 180^\circ$  or 10 ms) and three-level waveform (where  $\delta = 134^\circ$  or 7.5 ms) of the PV and wind power hybrid inverter, their average CTHD are 19.84% and 7.56%, respectively. Hence the improvement in the average CTHD obtained when a three-level waveform of the PV and wind power hybrid inverter is used will be about 62% if compared with the square wave.

### Conclusion

According to result shown, the proposed topology can be applied to the single phase PV and wind power hybrid inverter, from the square wave and three-level waveform developed can be summarized as below:

1. The Solar irradiance and temperature will effect on the PV array voltage. The wind speed will effect on the wind power generation voltage. The voltages are used to charge the battery that controlled by the hybrid controller circuit.
2. For the load of 20 W 220 V 50 Hz AC water pump, AC load rms voltage and current are higher when the single phase PV and wind power hybrid inverter is formed as AC square wave than as AC three-level waveform. It indicates that the AC waveform which is formed by the PV and wind power hybrid inverter will effect on AC load rms voltage and current.
3. The current harmonic spectrum is lower when the single phase PV and wind power hybrid inverter is formed as AC three-level waveform than as AC square wave. Average CTHD of the square wave is 19.84% and average CTHD of the three-level waveform is 7.56%. Hence the improvement in the average CTHD obtained when a three-level waveform of the PV and wind power hybrid inverter is used will be about 62% if compared with the square wave. It indicates that the single phase PV and wind power hybrid inverter is formed as AC three-level waveform is better than as AC square wave.

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