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IMPROVING KWH-METER PERFORMANCE AT PV ON GRID SYSTEM BY MULTIPLYING THE NUMBER OF SAMPLING SIGNAL

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ABSTRACT

The PV system is integrated with a low-voltage power network requires an inverter to convert the generated DC voltage by PV systems into AC voltage, and kWh-meter to measure the energy delivered by PV systems to the power grid . The latest generation inverter uses high frequency switching method to reduce the dimension and to improve the efficiency of the inverter. However, this high frequency switching raises the harmonics distortion flowing into the power grid and kWh-meter, and cause significant measurement errors in digital kWh-meter. This study intends to overcome the measurement error by the method of adjusting the frequency of sampling signal in kWh-meter digital with the switching frequency of the inverter. First, kWh-meter tested with a variety of inverter switching frequency to obtain the minimum value of the switching frequency which affected the measurement results of digital kWh-meters. Then kWh-meter measurement results corrected by sampling the signal according to the switching frequency of the inverter. The proposed method is evaluated by simulation LAB-VIEW and confirmed by experimental results. The proposed method is able to maintain the performance of kwh-meters on inverter switching frequency in range 3kHz -150kHz.
Keywords: *Digital kWh-meter, Error Measurement, High Switching, Inverter, Sampling Time*

1. INTRODUCTION

Alternative energy and renewable energy has an important role in fulfilling the needs of electrical energy. This is due to the use of fossil fuels for conventional power plants in the long term deplete sources of petroleum, gas, and coal which today has been diminishing. In an effort to reduce reliance on fossil fuels and environmental awareness, it has been a need to increase the efforts of electricity generation by using alternative energy and renewable energy, such as solar energy, wind energy, sea wave energy, micro hydro, biomass and Fuel Cell.

The growth of power generation using renewable energy connected to the grid has increased, such as wind power and PV. In the last few years, the development of PV technology connected to grid has increased and will become a trend in the future. PV capacity growth significantly over the last few years, led to more research focused on large-scale PV side effects when connected to the grid [1]. The main technical impact of large-scale PV plants on the grid to note is about power quality, power flow control, stability in voltage and frequency, the system test on environment, the revised code and standard on delivery to the grid, new requirements for technology simulation as well as some impact on the distribution system [2,3].

In PV systems connected to PV grid allows to transfer (selling) power to the grid when PV has excess power, resulting in action on transfer-receive delivery of electricity between power producers (using renewable energy) and consumers and with the local power company as the owner of the grid. This action need a transaction tool in form of measuring instrument of electrical energy (kWh-meter) which is used to inform of electrical energy that transferred by the power producer to the load and to the grid, thus obtained a reference for determining the selling price of electricity. KWh-meter is a device for measuring electrical energy, which measures the power consumption within a certain time.

Harmonic voltage and current harmonics, unbalanced currents and voltages of the load affects the accuracy of kWh meters. Extent of the deviation depends on the load harmonic [4]. Measurement error (-10.09% up to + 0:52%) occurred in 9 pieces of three-phase kWh-meter and 3 single phase electromagnetic kWh-meter when measuring

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energy from the load current harmonic simulation of more than 80% (ITHD > 80%) and voltage harmonic of more than 2% (VTHD > 2%) [5].

The use of digital kWh-meter is recommended especially for medium and large customers, because the accuracy and sensitivity of digital kWh-meter higher than electromagnetic kWh-meters, where there is a difference occurs in the measurement of (+ 0.5% - 1%) during the two kind of kWh-meters are used to measure energy consumed by the load [4].

Besides of kWh-meter, PV systems connected to grid are also require an inverter to convert the DC voltage generated by PV into AC voltage . This inverter uses a method of high switching frequency to obtain a sinusoidal voltage form (almost).

The use of high switching frequency up to 200 kHz on the PV system connected to the grid (Figure 1) allows the power losses and the dimension of the inverter becomes smaller, thus increasing the efficiency of the inverter [6].

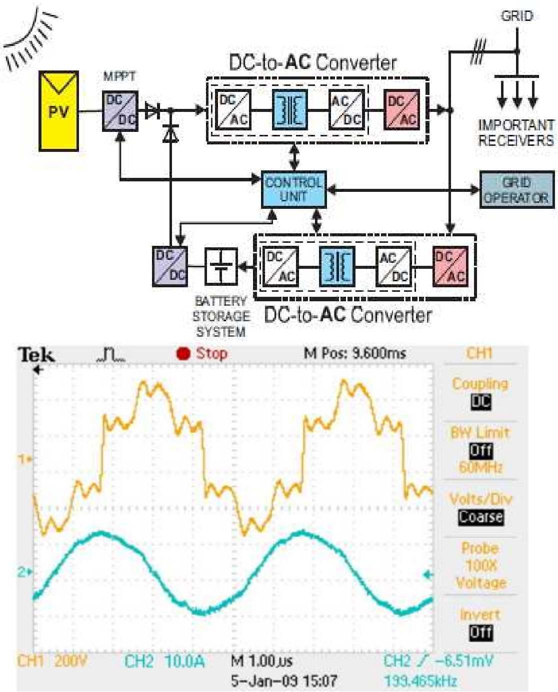

Figure 1. Implementation Of Inverters In PV Systems Connected To The Grid (Top) With A High Switching Frequency (Below) [6]

But the switching frequency in the range of 3 kHz to 150 kHz has caused kWh-meter measurement errors up to 40% of the actual value [7]. This because of no synchronization between the sampling frequency of the analog signal into a digital signal with a switching frequency of the inverter.

MGS technique has a lower computational burden in comparison with the DFT and FFT algorithms (Figure 2). Application of the undersampling strategy to reduce the hardware requirement and processing power to a lower level [8].

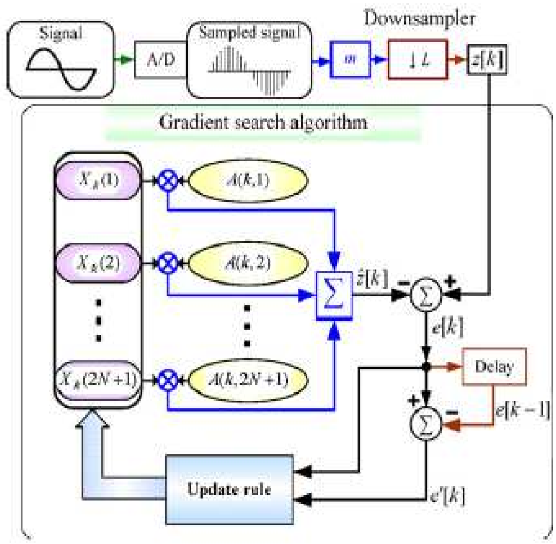

Figure 2. Algorithm Estimation Harmonic/Interharmonic On-Line

2. ACCURACY KWH METER DIGITAL

Electrical energy is calculated based on power consumption within a certain time or a multiplication between power and time. There are two kinds of tools for measuring electrical energy, those are kWh-meter to measure the active power consumption per hour and, kVARh-meter to measure the reactive power consumption per hour. To measure the electric energy, required a rating of: voltage, current, power factor and time. Rating of active power (P), reactive power (Q) and effective power (S), is:

$$P = V_{rms} I_{rms} \cos(\theta - \phi) \quad (1)$$

$$Q = V_{rms} I_{rms} \sin(\theta - \phi) \quad (2)$$

$$S = V_{rms} I_{rms} \quad (3)$$

Active power on a non-sinusoidal wave in the frequency domain is:

$$P_i = \sum_{n=0}^{N} I_n V_n \cos\alpha = P_0 + P_1 + P_H \quad (4)$$

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Where P_o is the DC active power, P_1 is the active power at the fundamental frequency and P_h is the active power at harmonic frequencies.

Based on active power can be calculated the amount of electrical energy (W) which is used in a certain period of time:

$$W = \frac{\Delta t}{3,6x10^6} \sum_{i=1}^{N} P_i \quad (5)$$

In making measurements need to consider several things, including accuracy, precision, sensitivity, resolution, error (gross, systematic, random). Accuracy is the closeness value read at the gauge against the actual value on the measurement object. For digital measuring instruments, the measuring results depends on the accuracy of measuring instruments and accuracy of external components attached to them. Instrument digital kWh-meter consists of a Voltage Transformer (VT) and Current Transformer (CT) to lower the voltage and current, Signal Conditioning (SC) and Analog-Digital Converter (ADC) to convert analog signals into digital signals, and display screen to display the results measurements (Figure 3).

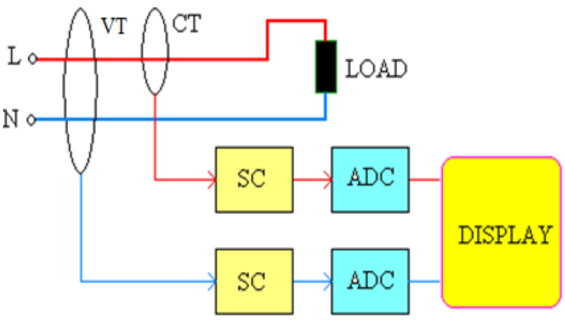

Figure 3. Diagram Block kWh-meter Digital

The ADC's process consists of the sampling processes, filters, quantization and encoding. Analog signal which is a continuous signal in time function and amplitude, will be sampled into discrete and filtering to avoid aliasing. This signal quantized into level 2^n, where n is the number of bits. Then do the coding with discrete representing the amplitude of each signal is quantized into a binary sequence of each bit.

In this process occurs rounding of numbers that affect the value of the binary number. The analog time signal can be written as follows:

$$Xa(t) = A \, Cos\,(\omega t + \Theta) = A \, Cos(\,2\pi f t + \Theta\,) \quad (6)$$

Where A is the magnitude, f is the frequency, Θ is the phase

t is time. If t = nT, then the sampling process Xa (t) is converted into X (n) = Xa (nT).

If this signal being sampled with a frequency Fs, then the discrete time signal will be obtained by:

$$X(n)=A \, Cos(2\pi n \, F/F_s + \theta) \quad (7)$$

Aliasing can affect the accuracy of a digital measuring instrument, because it can result in the difference waveform between the sampled signal and the actual signal. To avoid aliasing, thus is required minimum flow rate sampling (Nyquist rate), by:

$$F_s > 2F \quad (8)$$

It is therefore necessary that the sampling time as short as possible, in order to obtain a signal which approximates the shape or the actual value [9].

In the process of quantization, error can occur in the appearance of signal within a continues-value, with a set of levels of discrete finite values called quantization errors or noise quantization. Quantization operation on sample x (n) as Q [x (n)] and xq(n) indicates the output series of samples been quantized at the output of quantization. Thus, the quantization error is the eq (n) series which is defined as the difference between the quantized value and the actual value of the samples:

$$eq(n) = xq(n) - x(n) \quad (9)$$

Accuracy of digital measuring instrument is influenced by the number of bits (n) quantization level and full-scale (I_{fs}) on ADC's process that generates quantization error (ε_{Qn}) of [9]:

$$\varepsilon_{Qn} = \frac{1}{2}\left(\frac{I_{fs}}{2^n - 1}\right) \quad (10)$$

This error affects the resolution of the measuring instrument, by :

$$\varepsilon_{In} = \left| \frac{I - \varepsilon_{Qn}}{I} \right| x100\% \quad (11)$$

While the resolution of kWh-meter (ε_{Wn}) is calculated based on the value of the rms Current resolution (ε_{In}) divided by the number of sampling per second (Fs):

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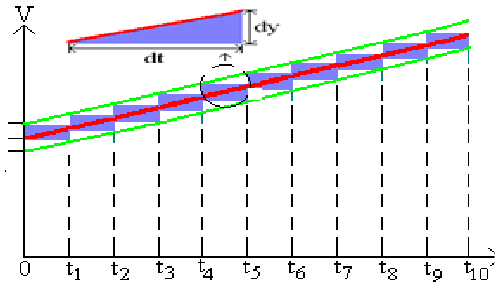
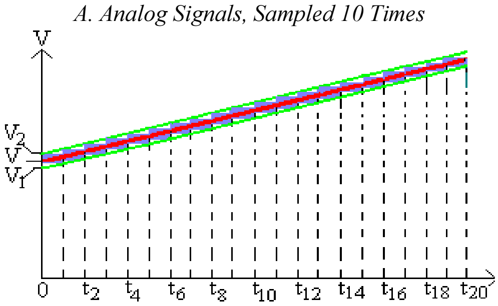
$$\varepsilon_{Wn} = \frac{\sqrt{\varepsilon I_n^2}}{\sqrt{F_s}} \tag{12}$$

3. DIGITAL KWHMETER ACCURATION IMPROVEMENT

Kwh-meter used in PV systems connected to the grid having measurement error due to the high level switching frequency on inverter. This can be overcome by an increase in the frequency of sampling signals on the kWh-meter in accordance with a switching frequency of the inverter.



A. Analog Signals, Sampled 10 Times



B. Analog Signals, Sampled 20 Times

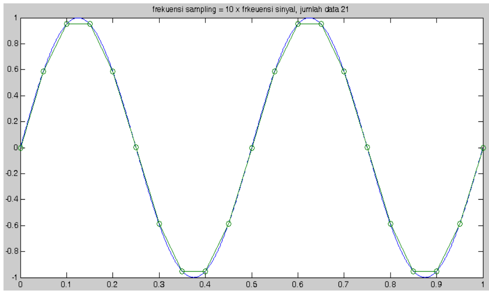
Figure 4. Various of Signals Sampling

Illustration of the relationship between error value (ε_s) with time sampling described by Figure 2, where the value is equal to the area of triangle ε_s (Figure 4a), that is equal to:

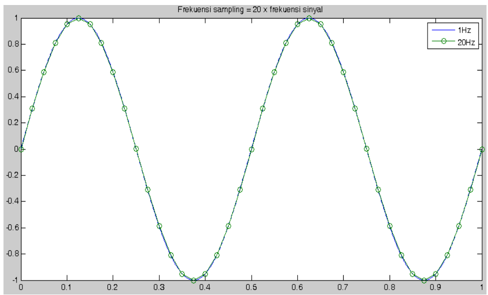
$$\varepsilon_s = 0{,}5\ dydt \tag{13}$$

The red line in Figure 4a is the actual signal to be measured (V). This signal is sampled 10 times at intervals t / 10 and produced two green lines with value V1 (less than V) and the value of V2 (over V). This means that there is a difference in value between the actual signals with the measurement signal. Difference value indicates the level of measurement error. This difference become smaller when the signal is sampled within a shorter time (t / 20) or doubled to 20 times, and resulting measurement signal that approach with the actual signal (Figure 4b).

Similarly, the sinusoidal wave is depicted 10 times (Figure 5a) and 20 times the fundamental frequency (Figure 5b). The greater amount of sampling, acquired waveform (green color) come closer to the actual shape (blue color).



a. Sinusoidal Wave, Sampled 10 Times



B. Sinusoidal Wave, Sampled 20 Times

Figure 5: Sinusoidal Wave is Sampled 10 Times and 20 Times of the Fundamental Frequency

The steps of the process are the appropriate sampling signals for reducing electrical energy measurement errors, repair of electrical energy measurement error due to the high switching frequency, validation against simulation which was made.

The order of processing of analog signals into digital signals can be seen in the flowchart below (Figure 6). The analog signal is converted into a digital signal through a process of sampling a signal, then quantized and coded, in order to obtain a digital signal output. This conversion results in comparison with the reference signal to obtain an error. If an error is generated not qualify, then the signal sampling process is repeated.

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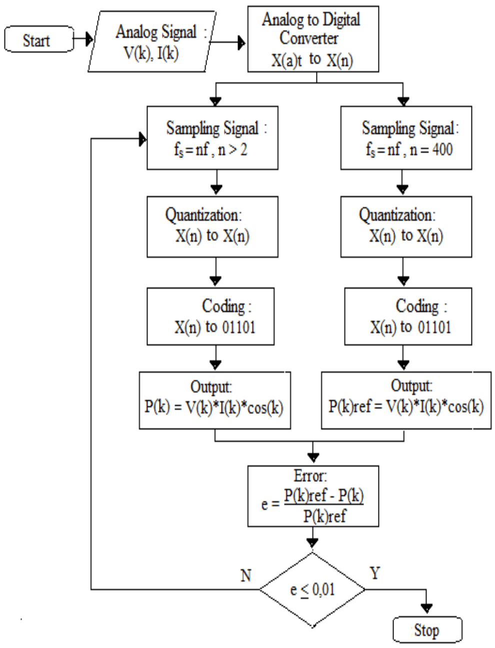

Figure 6. Algorithm correction of measurement error of kWh-meter

4. SIMULATION RESULT AND DISCUSSION

A single phase voltage source of PV system using a high switching frequency inverter is simulated by a multilevel waveform obtained from the modified sinusoidal wave in which the switching frequency can be set by selecting the number of bits.

If the number of bits is 4 with a frequency of 50 Hz voltage source, then a full-wave travel time is 20 ms. The amount of the voltage step is, n = 2^4 = 16. Thus, the travel time of one step is 1.250 µs. So, the switching frequency of 800 Hz voltage source.

In the same way obtained another switching frequency values of the number of bits (16-24). The results of calculations with different number of bits can be seen in Table 1, where the greater the number of bits, the greater the switching frequency.

Table 1. The Relationship Between The Number Of Bits With The Switching Frequency

Number of Bit	Number of Levels	Switching Frequency, F_s (kHz)
4	16	0.8
8	256	12.8
12	4,096	204.8
16	65,536	3,276.8
20	1,048,576	52,428.8
24	16,777,216	838,860.8

In addition, the selection of the number of bits also determines the number of level / step and the magnitude of the voltage level that affects the waveform. For example, the full-scale voltage of 5V with a number of bits 4, then it is obtained voltage level at 333.333 mV with multilevel waveform as shown in Figure 7 a green line, where the wave shape is different from the original shape, ie. sinusoidal (color lines yellow).

Comparison of quantizing a sinusoid to 64 levels (6 bits) and 256 levels (8 bits), the additive error created by 6-bit quantization is greater than the error created by 8-bit quantization.

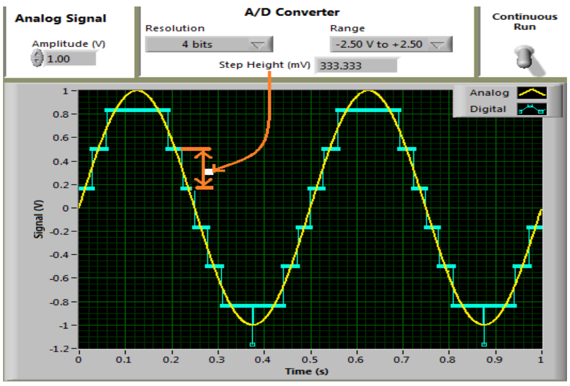

Figure 7. Waveforms Multilevel With A Resolution Of 4 Bits

Error of measurement of kWh-meters depending on signal resolution and sampling frequency of the signal (F_s) in ADC process. On this simulator is used the signal (wave) multilevel with different resolutions, ie 4 bits - 24 bits. This signal is sampled as many as n times the fundamental frequency to obtain measurement's error of kWh-meter maximum of 0.01% (e ≤0.01%) in accordance with the correction algorithm of measurement error of kWh-meter (Figure 6).

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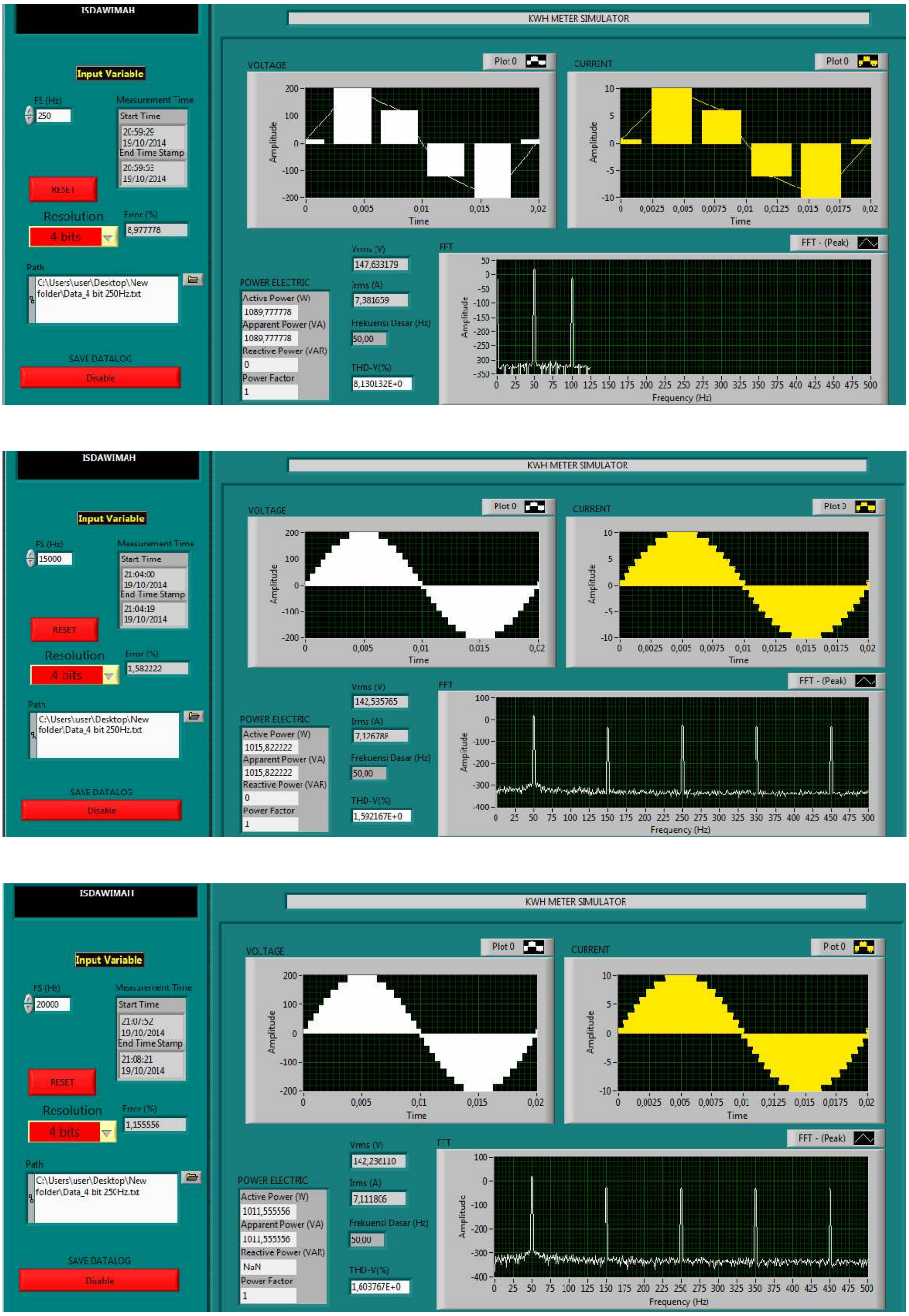

Figure 8. Multilevel Wave With Fundamental Frequency Of 50 Hz And A Resolution Of 4 Bits Sampled As Many As: A. 5 Times Or 250Hz, B. 300 Times Or 15000 Hz, C.400 Times Or 20000Hz

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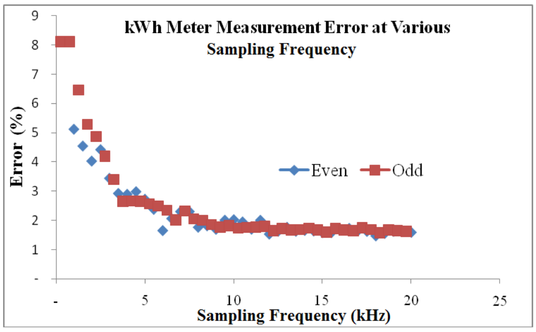
Figure 8a is a multilevel waveform with a resolution of 4 bits which are sampled with a frequency of 250 Hz (5f) and resulting effective voltage 147.63V with current 7.382 A when connected to a resistive load 20Ω, so the power used (P_1) is 1.089 kW. When compared with Figure 8b, where the same waveform (resolution of 4 bits) is sampled with a frequency of 15 kHz (300f), then obtained effective voltage 142.5 V with the current 7.127 A, so that the power used (P_2) is 1.0158 kW.

The results of these measurements compared to the reference power P_{ref}. P_{ref} is obtained from the multiplication of the rms current, rms voltage and power factor. In this case is used the effective voltage references of 141,12V with resistive load 20Ω, then P_{ref} is 1kW. P_{ref} used as a reference to calculate the measurement error of kWh-meter on numbers of other sampled.

With the sampling frequency of 250Hz, then resulting measurement error of 8.9%. This error drops to 1.58% when the signal is sampled with a frequency 15 kHz.. An error of measurement of 1.1 % obtained when signals is sampled with the frequency of 20 kHz (Figure 8c).

Signal with the resolution of 4 bits being sampled with varying in value fs to obtain the smallest error. See Figure 9a, the rate of lowering an error against frequency sampling is more linear at the value of Fs odd (red color) compared at the value F_s even (blue color). Similarly on sampling signals with a resolution of 24 bits (Figure 9b). From Figure 9 also obtained the relationship between the Error and the Resolution, where the greater the resolution, the smaller the error.



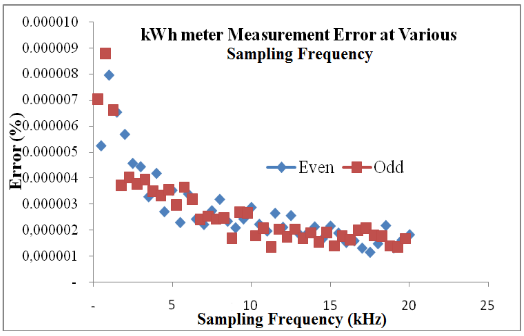


Figure 9: Graph Of The Relationship Between The Sampling Frequencies Of The Measurement Error Of Kwh-Meter, Resolution: A. 4 Bits (Top), B. 24 Bit (Bottom)

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6. CONCLUSION

In general, the inverter is non-linear loads that cause harmonics on the voltage source. This paper discussed on the contrary, that is the inverter as part of a voltage source that has given rise to harmonics in the load and kwh meter.

In the on-grid PV systems required special Kwh meter, because this system uses an inverter with high switching frequency that can affect the measurement results kwh meter.

The method used to overcome this problem is to conduct the sampling-signals according to the switching-frequency of inverter in order to obtain complete information signal, so that measurement errors can be reduced.

The statement which is said an increase in the frequency of the signal sampling can reduce measurement error kWh-meter, not entirely true.The simulation results indicate the presence of fluctuations in the value of the measurement error kWh-meters when the sampling frequency of the signal is increased.

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