ACTIVE POWER AND ENERGY REVENUE MEASUREMENT AT SIMULTANEOUS CONSUMPTION UNDER A PROSUMER MODEL

Lucas Alecsander Ataide Gomes da Silva [a], Jiri Drapela [b], Jan Klusáček [c]

[a] Departamento de Engenharia Nuclear, Escola Politécnica, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brasil, lucasalecsander10@poli.ufrj.br

[b] Faculty of Electrical Engineering and Communication, Brno University of Technology, Brno, Czech Republic, drapela@feec.vutbr.cz

[c] Electrical Power Engineering, Faculty of Electrical Engineering and Comunication, Brno University of Technology, Brno, Czech Republic, klusacekj@vut.cz

Abstract. This paper intents to a critical revision of power components theories taking into account physical merits of active power and energy revenue at simultaneous consumption and generation under nonsymmetric and time-variable conditions. Using MATLAB's tools, as Simulink, to simulate sinusoidal wave, in a prosumer model, in order to get the Root Mean Square (RMS) values for current and voltage, under frequency and amplitude varying signals, a way to measure the active power, and estimate the frequency using the zero-crossing method.

Keywords. Active power, rms, frequency estimation, zero-crossing, MATLAB.

1. INTRODUCTION

Few decades ago, majority of electrical loads prior to the use of current continuous or alternating sinusoidal. As a result, the concepts of active power were associated with this ideal form of voltage and current.

Revenue metering is measuring the usage of a specific utility service like heat, electricity or gas (Tan, Lizhe, and Jean Jiang et al, 2018). For alternating current (AC) measurement, the power factor (PF), which is the ratio of active power (AP) consumed by a component to the apparent power in an AC circuit or total power (S) according to the equation (1). Apparent Power or total power (S) is the combination of reactive power and active power, and it is the product of a circuit's voltage and current, without reference to phase angle, equation (2).

$$P = \frac{AP}{S}$$ **(Error! No sequence specified.)**

$$S = V \times i \qquad (2)$$

The PF introduces complexity on equation (3):

$$watts = volts \times amps \times PF \qquad (2)$$

This measurement of AC power is referred to as active power. Also, study intents to measure active power and energy revenue at simultaneous consumption and generation under nonsymmetric and time-variable conditions. To develop an evaluation of metrics for revenue meters in order to measure passing active energy, a study about power components theories, nonlinear, dynamic and active distribution systems was performed. To reach the main goal the MATLAB and Simulink tools were used. The first step was to review concepts of static revenue meters' metrics to presumptions for instrumentation.

Simulink tools can simulate a prosumer model, which consists in resistors (R), inductors and capacitor connected in series and parallel. And the data was imported to MATLAB where the codes were performed in order to calculate the Root-Mean-Square (RMS), which is the value of the direct current that dissipates the same power in a resistor, and estimate frequency in a sinusoidal wave using Zero crossing method (simplest method of frequency estimation) which is also used in speech processing to estimate fundamental frequency (Chen, Hao, Fangxing Xu, and Jiangyuan Li et al, 2018).

The frequency (*f*) can be calculated using the equation (4):

$$f = \frac{1}{\Delta T} \tag{4}$$

A sine wave is the most fundamental type of signal in communication systems, navigation systems and power systems.

It has three parameters: amplitude, phase and frequency, phase and frequency are interconnected by instantaneous frequency (IF), as presented on equation (5).

$$IF = \frac{\Delta \Phi}{\Delta t} \tag{5}$$

The topic for this work is aimed to critical revision of power components theories taking into account physical merits of measured phenomena related to nonlinear, dynamic and active distribution systems.

In order to revise the power components in realistic environment, the model of the three-phase prosumer with typical and potentially critical appliances is suitable for generation of realistic voltage and current waveforms.

2. RESEARCH METHODS

2.1 PERFORMING AC CIRCUIT ON SIMULINK

A parallel circuit was developed on Simulink using:

A Three-Phase Programable Voltage Source to implement a sinusoidal wave with time variation for an amplitude of 800 and frequency of 50 Hz, considering a sept magnitude of -10Hz for frequency and variation timing of 0.5 seconds in 1 second, which we used later to calculate the V_{RMS} and i_{RMS} for each frequency;

For a balanced consumption there are 4 resistors (one of them is related to the ground) on horizontal, also a current measurement to later export the data to MATLAB and after the power-over-cable (PoC) 3 resistors on vertical as represented on **Fig.1**.

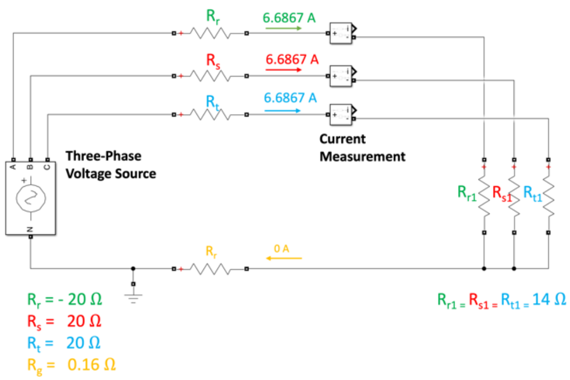

Fig. 1 – AC circuit

On **Fig.2** the resistor on vertical were replaced for variable resistors and considering a step 0.3 second for time variation, in order to check if the sinewave would show a different behavior.

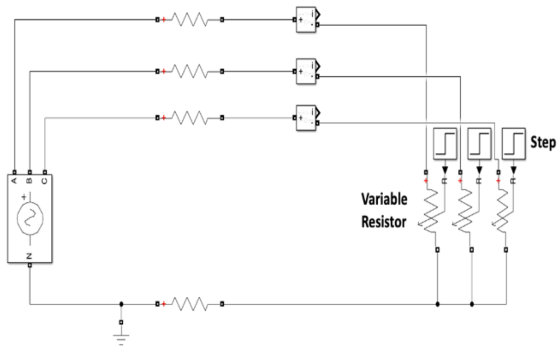

Fig. 2 – AC circuit with variable resistors

2.2 DEVELOPING THE CODE ON MATLAB

On MATLAB was possible to use all the data exported from Simulink in order to get the rms in each input and then plot the signal previous established.

2.3 ZERO-CROSSING METHOD AND FREQUENCY ESTIMATION

The zero-crossing (ZC) estimator operates by detecting zero crossings in the real components and storing the estimated time and phase of the zero crossing points to a coordinate. It occurs twice during each cycle (Liao, Yizheng et al, 2011).

Considering it an accurate estimation with minimum number of samples. In other words, since the sinusoidal wave cross the x-axis during each cycle, there is a way to count the number of crossing and divide by two, and then divide it by the observation window size (which is the time that our simulation takes), reaching the frequency in Hertz (Yegnanarayana, Bayya, and K. Sri Rama Murty et al, 2009), which was performed on MATLAB code.

2.4 ROOT MEAN SQUARE VALUES

The RMS value gives the amount of AC power drawn by a resistor. And the value of voltage or current varies with respect to time.

In this case is possible to find the RMS value above the signal to find power, can be used the analytical method considering the equation (6) for a sinusoidal wave using the voltage of the peak (V_{peak}), which is the maximum peak value of voltage waveform in with a period of T.

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T V^2{}_{peak} cos^2\,(2\pi t/T)dt}$$

$$V_{RMS} = \frac{V_{peak}}{\sqrt{2}} \qquad (6)$$

The graphic method was implemented on MATLAB taking the maximum significant number of points before the wave cross the 0 x-axis to result high accuracy.

For i_{RMS} is exactly the same procedure using the algebraic method and following the equation (7), where i_0 is the peak value current.

$$i_{RMS} = i_0 sin(2\pi t/T)$$

$$i^2{}_{RMS} = i^2{}_0 sin\,(2\pi t/T)$$

$$i_{RMS} = \frac{i_0}{\sqrt{2}} \qquad (7)$$

2.5 APPARENT POWER AND ACTIVE POWER

Apparent power (S) is the total power flowing in an AC system to a load and is measured using voltage and current as in equation (7) and the unit is given as volt-amps.

Active power or true power (P) is the actual amount or portion of power being used or dissipated, always equal to or less than the apparent power and it is measured in watts, which can be calculated using the equation (8) combining equations (6) and (7), considering that every RMS voltage and current value are the same.

It is also possible to calculate the power factor (PF) using the ratio of active power to the apparent power in equation (10). The PF is a number between 0.0 and 1.0.

$$S = 3V_{RMS} \times i_{RMS} \qquad (8)$$

$$P = 3V_{RMS} \times i_{RMS} \times \cos\,(\phi) \qquad (9)$$

$$PF = \frac{P}{S} \qquad (10)$$

3. RESULTS AND DISCUSSION

3.1 AC system on Simulink

After performing the simulation on Simulink and exporting the data to the workspace on MATLAB is possible to plot a graph on **Fig. 3** and **Fig. 4** where it shows how currents and voltages behave in a sine wave. Also, the sine wave presented the same behavior for each simulation.

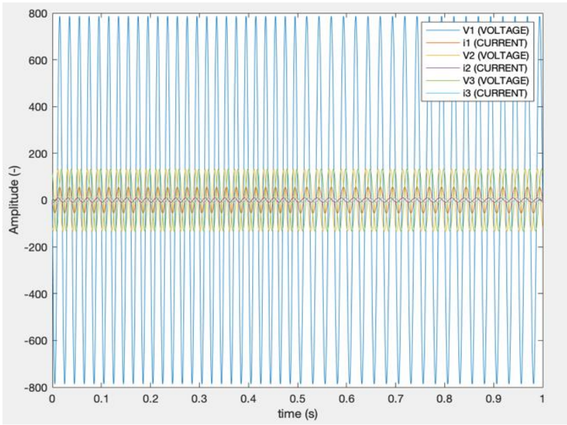

Fig. 3 – Amplitude vs time

3.2 Zero-Crossing method and Frequency Estimation

Performing the ZC method using the MATLAB code was possible to calculate the FE using the equation (3) according to the **Fig. 3**.

The graphs bellow describes voltage vs time; current vs time; power vs time; and Zero-crossing method. In order to estimate frequency, third graph, to interpret the signal varying the voltage and current with respect to time it was possible to find the RMS values, which is presented in the next topic.

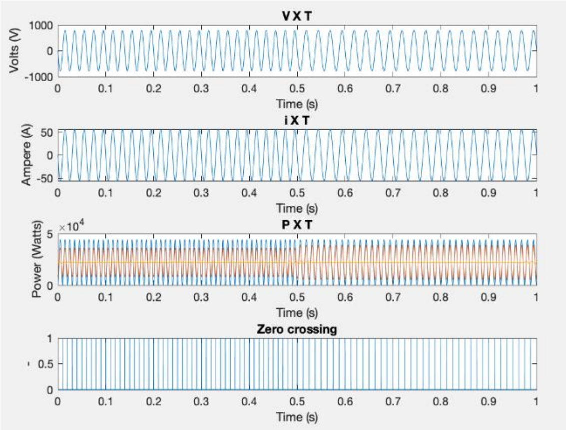

Fig. 4 – MATLAB's output

Considering the equation (3) was possible to calculate the estimated frequency for each cycle: 49.50 Hz.

3.3 Root Mean Square Values

For a sine wave signal is not possible to use the instantaneous value to calculate power, assuming that the instantaneous value varies. The **Fig. 4** presents the RMS values for current and voltage in a sinewave (presented on **table 1** and **table 2**), which are constant during the whole simulation.

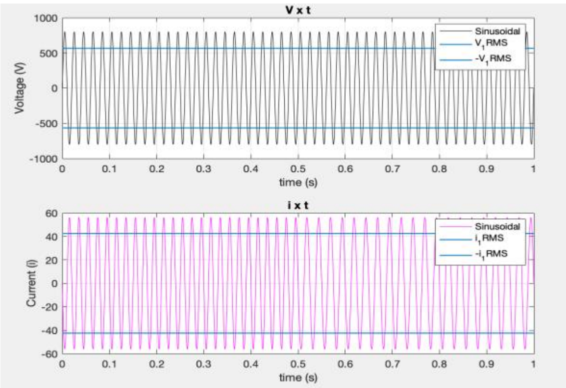

Fig. 5 – Voltage and current RMS values

Tab. 1 – Current RMS value

i_{1rms} (A)	i_{2rms} (A)	i_{3rms} (A)
42.4260	42.4260	42.4260

Tab. 2 – Voltage RMS value

V_{1rms} (V)	V_{2rms} (V)	V_{3rms} (V)
565.0486	565.0486	565.0486

3.4 Apparent Power, Active Power and Power Factor

To reach each value the RMS values for voltage and current were used fin this purpose. On **table 3** below presents values of Apparent Power, Active Power and Power Factor.

Tab. 3 – Results exported from Simulink

Apparent Power (VA)	Active Power (W)	Power Factor
71998	71823	0.99

The power factor is below 1.0 so it requires a utility to generate more than the minimum volt-amperes necessary to supply the Active Power.

4. Conclusion

The results were provided by MATLAB and Simulink tools, which graph the values. There are many ways to estimate the frequency and Active power of a sine wave, from Fast Fourier Transform to Zero-crossing methods. For a sinusoidal signal is not possible to use the instantaneous value to calculate power, assuming that the instantaneous value varies.

Also, RMS values still are constants for a sine wave signal. To accurate estimation all the samples were considered for the Zero-crossing method.

The goal of this paper is to contribute to the development of systematic system of critical evaluation of the power components measurement technics and evaluation of various power theories.

5. Acknowledgement

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6. References

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