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Energy Efficiency Analysis in Static Converters using IEEE 1459

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OUTLINE

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INTRODUCTION

- Technological advances and the uncontrollable ability of human beings to generate ideas allow the development of equipment and devices that require power to operate.
- The vast majority of those artefacts need to be fed by power devices electronically controlled, which are designed and constructed to minimize electricity consumption.
- The estimation of the efficiency of these components can be subjective.
- The IEEE 1459 standard raises a logical discrimination of powers.

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INTRODUCTION

- Methodology for the analysis of energy efficiency in power static converters on discrimination of electric power in systems where it is evident the existence of harmonic in waves of voltage and current (IEEE 1459 Standard).

- Standard definitions for the measurement of electric power quantities: Sinusoidal, non sinusoidal, balanced or unbalanced conditions.

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INTRODUCTION

- Different works has been developed using this Standard:
  1. **Pigazo and Moreno in 2007**: Time-domain implementation without low pass filters and a recursive averaging algorithm of the standard definitions.
  2. **Cataliotti et al. in 2008**: A virtual instrument based on a time domain technique for the detection of the fundamental and harmonic components of voltages and currents.
  3. **Cataliotti and Cosentino in 2009**: A single-point method for the identification of prevailing loads in power systems for single-phase and three-phase applications downstream or upstream from the metering section.
  4. **Cataliotti and Cosentino in 2010**: An approach for the detection of disturbing loads in distorted and/or unbalanced three-phase power systems (three-wire and four-wire) .
  5. **Grau et al. in 2010**: An power compensator for the 1459 Standard by using moving window discrete Fourier Transform in order to calculate the reference currents and a time-efficient current regulator.
  6. **Newton and Cardoso in 2012**: An approach for the harmonic decomposition of voltage and current by using the Kalman Filter combined with a frequency detection algorithm.
  7. **Pobladar and Lopez in 2013**: A methodology for the analysis of distribution systems using the power definitions in the Standard under sinusoidal, non-sinusoidal, balanced and unbalanced situations.

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THEORICAL BACKGROUND

➢ IEEE Standard 1459-2010

- In this standard, power quantities of an electrical system are classified according to the conditions presented in the source or circuit load.
- Currently, this classification is necessary when there are non linear loads that generate distortion over the voltage and current waves in electric circuits.
- As solution this Standard provide a recommendation to discriminate the power.
- This article suggest a methodology to determine the efficiency in static power converters.

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THEORICAL BACKGROUND

$$v = \sqrt{2}V\sin(wt) \quad (1)$$

$$i = \sqrt{2}V\sin(wt-\theta) \quad (2)$$

$$p = vi \quad (3)$$

$$p = p_a + p_q \quad (4)$$

p_a : Instantaneous active power

p_q : Instantaneous reactive power

$$p_a = VI\cos(\theta)\left[1-\cos(2wt)\right] \quad (5)$$

$$p_a = P\left[1-\cos(2wt)\right] \quad (6)$$

$$P = \frac{1}{KT}\int_{\tau}^{\tau+kT} p\,dt = \frac{1}{kT}\int_{\tau}^{\tau+kT} p_a\,dt = VI\cos\theta \quad (7)$$

This kind of power represents the rate of unidirectional flow of the energy from the source to the load

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THEORICAL BACKGROUND

$$p_q = -VI\sin\theta\sin(2wt) = -Q\sin(2wt) \quad (8)$$

$$Q = VI\sin\theta \quad (9)$$

$$S = VI = \sqrt{P^2 + Q^2} \quad (10)$$

$$PF = \frac{P}{S} \quad (11)$$

For a single-phase non-sinusoidal signal (voltage or current) in steady-state, the voltage and the power need to be expressed by two components, the power system frequency components and the remaining terms as in the equations 12 and 13.

$$v = v_1 + v_H \quad (12)$$

$$i = i_1 + i_H \quad (13)$$

$$v_1 = \sqrt{2}V_1\sin(wt - \alpha_1)$$

$$i_1 = \sqrt{2}I_1\sin(wt - \beta_1)$$

$$v_H = V_0 + \sqrt{2}\sum_{h\neq 1} V_h\sin(hwt - \alpha_h)$$

$$i_H = I_0 + \sqrt{2}\sum_{h\neq 1} I_h\sin(hwt - \beta_h)$$

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THEORICAL BACKGROUND

The corresponding rms values squared are described by the next equations:

$$V^2 = \frac{1}{kT}\int_{\tau}^{\tau+kT} v^2\,dt = V_1^2 + V_H^2 \qquad (14)$$

$$I^2 = \frac{1}{kT}\int_{\tau}^{\tau+kT} i^2\,dt = I_1^2 + I_H^2 \qquad (15)$$

$$V_H^2 = V_0^2 + \sum_{h\neq 1} V_h^2 = V^2 - V_1^2$$

$$I_H^2 = I_0^2 + \sum_{h\neq 1} I_h^2 = I^2 - I_1^2$$

The Total Harmonic Distorsion (THD) for voltage and current can be calculated as in the equations 16 and 17 respectively:

$$THD_V = \frac{V_H}{V_1} = \sqrt{\left(\frac{V}{V_1}\right)^2 - 1} \qquad (16)$$

$$THD_I = \frac{I_H}{I_1} = \sqrt{\left(\frac{I}{I_1}\right)^2 - 1} \qquad (17)$$

For the fundamental case, IEEE 1459 sugest the follow equation:

$$S_1 = V_1 I_1 \qquad (18)$$

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THEORICAL BACKGROUND

For non-fundamental case the purpose relation for the apparent power is:

$$S^2 = (VI)^2 = (V_1^2 + V_h^2)(I_1^2 + I_H^2) = \left(V_1 I_1\right)^2 + \left(V_1 I_h\right)^2 + \left(V_h I_1\right)^2 + \left(V_h I_h\right)^2 = S_1^2 + S_N^2 \quad (19)$$

Table includes a resume with the meaning of every term in the equation (19).

Total Nonfundametal apparent power (VA)	$S_N^2 = D_I^2 + D_V^2 + S_H^2$ (20)
Current distortion power (var)	$D_I = V_1 I_H = S_1 (TDH_I)$ (21)
Voltage distortion power (var)	$D_V = V_H I_1 = S_1 (TDH_V)$ (22)
Harmonic apparent power (VA)	$S_H = V_H I_H = S_1 (TDH_1)(TDH_V)$ (23) $S_H = \sqrt{P_H^2 + D_H^2}$ (24)
Harmonic distortion power (var)	$D_H = \sqrt{S_H^2 - P_H^2}$ (25)
Nonactive power (var)	$N = \sqrt{S^2 - P^2}$ (26)

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EXPERIMENTAL SETUP

As the overall aim is to establish a methodology for using the IEEE 1459 standard to calculate efficiency in static power converters is considered a combined a system between rectification and inverter topologies to measure parameters on AC input and AC output in a single phase case.

For this simulated system the following measurements as input and output parameters were undertaken

PARAMETER	DENOMINATION
THDv-i/ THDv-o	Voltage Total Harmonic Distortion
THDi-i/ THDi-o	Current Total Harmonic Distortion
V_{Ti}/ V_{To}	Total Voltage
I_{Ti}/ I_{To}	Total Current
S_{Ti}/ S_{To}	Total Apparent Power
P_{Ti}/ P_{To}	Total Active Power
Q_{Ti}/ Q_{To}	Total Reactive Power

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EXPERIMENTAL SETUP

- Considering the traditional method to estimate energy efficiency, the sinusoidal case proposed by the IEEE 1459, for the proposed rectification and inverter combined system can raise the analysis in two directions.

$$\eta_1 = \frac{S_{TO}}{S_{Ti}} \qquad (27)$$

$$\eta_2 = \frac{P_{TO}}{P_{Ti}} \qquad (28)$$

- The first proposal considers that the active and reactive power are required for the intrinsic system operation.

- The second proposal excludes the reactive power and considers only the active component, and the effective power utilization.

- To estimate efficiency of the proposed converter non-sinusoidal case which is suggested by the 1459 IEEE standard, it is used the following relationship:

$$\eta_{IEEE1459} = \frac{P_1}{S_{Ti}} \qquad (29)$$

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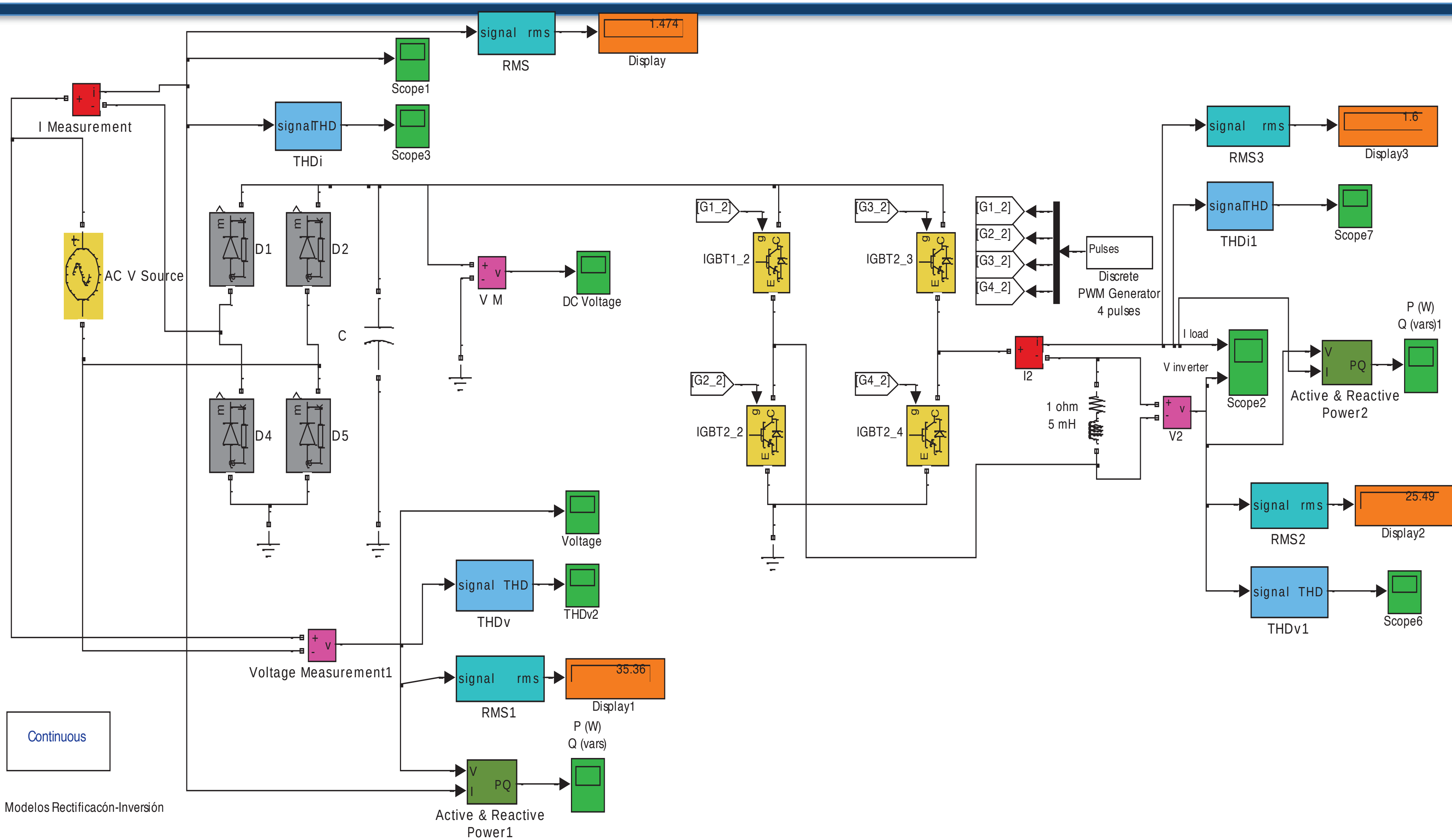
SIMULATION AND RESULTS



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SIMULATION AND RESULTS

As a result of the simulation values are:

Measured Parameter		
Parameter	INPUT	OUTPUT
THDv	0,001%	120%
THDi	160%	16%
V_T	35,36 V	25,49 V
I_T	1,474 A	1,6 A
P_1	-	24,95 W
Q_1	-	4,7 VAr
Calculated Parameter		
V_1	35,36 V	16,28 V
I_1	0,74 A	1,57 A
V_h	0	19,536 V
I_h	1,18 A	0,25
D_v	0	30,86
D_i	0	4,11
S_T	52,12 VA	40,78

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SIMULATION AND RESULTS

Therefore, the estimated efficiencies are:

$\eta_1 = \frac{S_{TO}}{S_{Ti}}$	**78%**
$\eta_{IEEE1459} = \frac{P_1}{S_{Ti}}$	**47%**

- The results shown that the estimate efficiency using the Standard IEEE 1459 provide a lower value efficiency compared with the current normal estimation.

- This is because the Standard includes inefficient power associated with the presence of harmonics in current and voltage signals, which are generated by the static converters into the process.

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CONCLUSIONS

- The classification of powers proposed by the IEEE 1459 standard to establish a methodology for estimating energy efficiency of a static power converter simulated in SIMULINK software platform was used.

- The measurement instruments used in the software allowed the estimation of each parameter required to understand the proposed methodology, which considers the active power of the fundamental component as the only effective parameter.

- In this regard it is noted that the estimated value is lower, so the analysis suggests that static conversion systems are less efficient power if the rules are applied rigorously.

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Thank you for your attention!