Simulation and dsPIC30F4011 based Implementation of a network analyzer instrument

Ines BEN SALEM, Lotfi TAGHOUTI

Abstract— Preliminary prototype of the (dsPIC30F4011) based complex network analyzer instrument is developed and investigated. High performance are required using multichannel multi-frequency measurement devices. Using this Digital Signal Controller offers much computational power for real-time signal processing, dedicated memory, IO controllers, flexible communication and peripheral interfaces at low cost and reasonable power consumption. Proposed solution is developed, described and discussed. Performance estimations, both from theoretical considerations, as well as from experimental investigation, are given. As a result, a very promising technical solution is developed. Main contribution of the current work has practical implementation and investigation of specific analog interfaces and corresponding firmware parts. Its implementation is based on the programming of an electronic card based on a Digital Signal Processor to read and record the harmonic current and voltage of a power supply and the power budget of a power grid.

Index Terms—Analyzer Network analyzers, Digital Signal Processor, harmonic current, Implementation.

1 Introduction

ELECTRICAL disturbances on the networks can have adverse effects on electrical equipment and building installations.

They are transitory in nature (seconds) or it is true power outages (several hours). They can cause damage to various degrees, ranging from one-time malfunction of some equipment until the blackout, causing productivity declines, significant loss of data, so, a cost in terms of Energy efficiency.

Generally, the quality of power distribution depends on the harmonic currents on the network, normal consequence of an electrical system to distribute power electronic loads. Specifically, the harmonic distortions are likely to cause high neutral current, and thus overheating of motors and transformers [1,2].

For monitoring the quality of delivered energy, professionals may already be equipped with dedicated service tools capable of performing essential measures to increase productivity. Network analyzers or power analyzers are used to identify voltage events difficult to detect and provide a reliable diagnosis of interference: voltage imbalance (dips, surges, outages ...), recorded waveforms, analysis of electrical harmonics active, reactive and apparent power, power factor, tangent, and peak factor.

If problems are detected early, it becomes possible to extend the life of equipment and materials involved, and prevent further breakdown in the future.

Network analyzers can obtain the main characteristics of the electrical network quality to treaties thereafter. A network analyzer can measure the voltage parameters, current, useful power and energy to a full diagnosis of an electrical installation. To locate, predict, prevent and resolve network performance problems on electrical power distribution systems.

Electrical power quality problems can cause malfunctions with serious consequences and excessive energy costs. The electrical power analyzer enables protect themselves by ensuring the quality of the delivered energy.

Existing solutions for realizing of the network analyzer include special chips [3, 4] and could be used for a large network but so expensive.

One solution could be developed using a programmable dsPIC, is probably more flexible, and cost efficient.

In the current work, a preliminary prototype of the (dsPIC30F4011) based network analyzer instrument has been developed and investigated. High performance are required using multichannel multi-frequency measurement devices.
It is based firstly, on a harmonic study, including the computation of the power factor of an electrical signal.

Spectral analysis of signals is done using a decomposition in Fourier series under Matlab / Simulink Simulations.
A second part presents the hardware implementation of the power analyzer in two stages: the realization of an acquisition card to receive electrical signals (voltage and current) from the network and then formats them to undergo the necessary treatment.

A third part is based on the programming of the DSPICDEM card and the Real Time test and display of the FFT.

2 Harmonics Analysis

2.1. Presentation standard

The standard EN 50160 characterizes the quality of the voltage supply. His objective is to define and describe the values characterizing the supply voltage provided such as frequency, amplitude, waveform and symmetry [5, 9, 10].

In normal operation, these features are subject to variations due to system load changes of disturbances from some equipment and the appearance of defects mainly due to external causes. Different disturbances treated by EN50160 are:

- Voltage dips and short interruptions
- surges
- Slow variations in the voltage
- Changes in grid frequency

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

- The voltage imbalance
- harmonics
- rapid changes in voltage
- flicker (flicker)

We present the following characteristics of the frequency and the voltage supplied by the public distribution networks as well as the harmonic tension.

- Frequency

BT and MT Supply Features (Rated Frequency: 50 Hz) Changes in grid frequency because of commissioned and non-production sites of service, Fig.1. For example, an average value of 10 seconds is fixed to 50Hz +4% / -6% for 100% of the time for Networks connected by synchronous connection to an interconnected system [6]. For a Networks without synchronous connection to an interconnected system (islands), 50 Hz ± 15% (42.5 - 57.5) for 100% of the time.

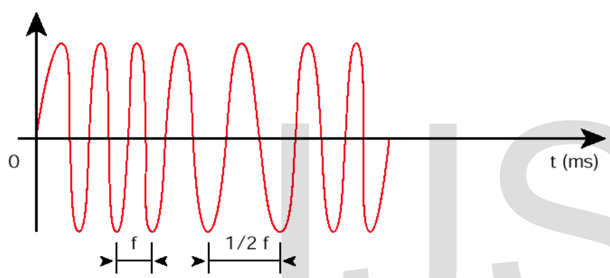


Figure 1 : Network frequency variation

- Standard Rated voltage (amplitude)

For three-phase system, the standard rated voltage amplitude is 230V inter-phases. In normal operating conditions, all effective values averaged over 10 minutes should be in the range +10% and - 15% [7].

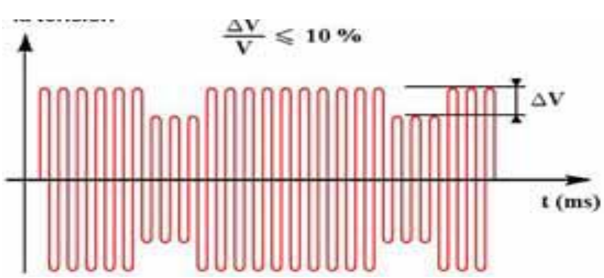


Figure 2 : Network voltage variation

- Supply harmonics

Normal operating conditions for each period of one week, 95% of RMS values of each harmonic voltage averaged over 10 minutes must not exceed the values in Table1 of the standard. In addition, the total harmonic distortion of the voltage supplied (including up to rank 40) should not exceed 8%. [8]

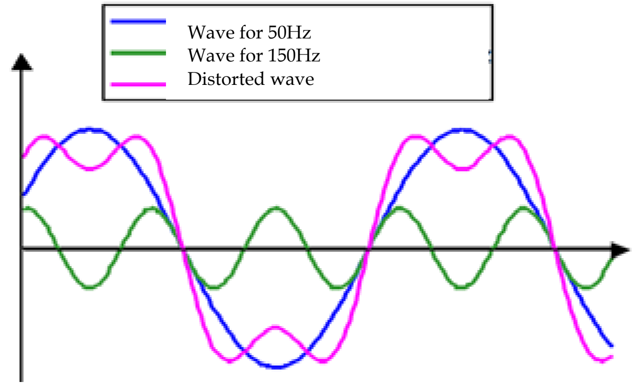


Figure 3 : Temporal representation of a distorted wave

The following table summarizes the values of harmonic voltages at supply points.

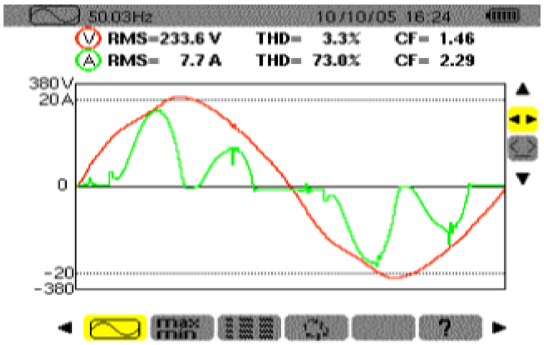
Table 1 : The values of the distorted wave

Odd Ranks No multiple of 3		Rangs impairs multiple of 3		Peer Ranks	
Rank	Harmonic voltage(%)	Rank	Harmonic voltage (%)	Rank	Harmonic voltage(%)
5	6	3	5	2	2
7	5	9	1,5	4	1
11	3,5	15	0,3	6	0,5
13	3	21	0,2	8	0,5
17	2	>21	0,2	10	0,5
19	1,5			12	0,2
23	1,5			>12	0,2
25	1,5				
>25	0,2+1,3*25/h				
Harmonic Distortion Rate (THD) : 8%					

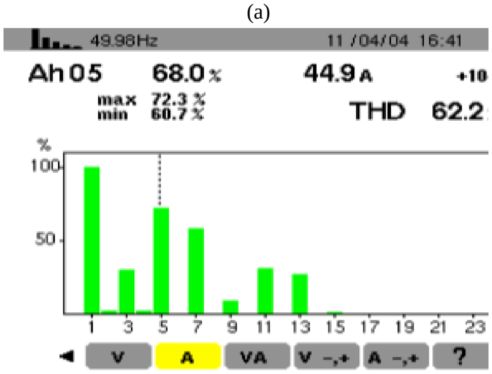
Even or odd rows: Harmonics are distinguished by their rank. Even rank harmonics (2, 4, 6, 8 ...), very often negligible in industry, are canceled due to the symmetry of the signal. They exist only in the presence of a continuous component. On the other hand, odd-numbered harmonics (3, 5, 7, 9...) are frequently encountered on the electrical network. It is also those that we seek to identify, quantify and limit in industrial electrical networks. Higher harmonics to the rank 25 are in most cases negligible.

For illustration, we will take the following example: When a signal is perfect, it is composed of a fundamental signal. Harmonics are multiple frequency components of the fundamental.

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518



(a)



(b)

Figure 4. (a) RMS value of current and voltage (b) Harmonic distortion rate computation using a network analyzer instrument

2.2. Power Factor computation

The computation of the power factor is based on the IEEE standard 1459-2010 [11]:

For a sinusoidal Source with linear charge:

$$FP = \frac{P}{S} = \cos\theta \qquad (1)$$

For a sinusoidal Source with nonlinear charge:

$$FP = \frac{P}{S} = \frac{\cos\theta_1}{\sqrt{1+THD_i^2}} \qquad (2)$$

For a no sinusoidal Source, current and voltage admit harmonic components. They have two distinct components: fundamental components v_f and i_f, and the remaining terms v_H and i_H containing all the harmonics THD_I and THD_V.

$$FP = \frac{P}{S} = \frac{FP_1(1+\frac{P_H}{P_1})}{\sqrt{1+THD_I{}^2+THD_V{}^2+(THD_I * THD_V)}} \qquad (3)$$

2.3. Numerical Modelling and Simulation

In this part, we aim to compute the Spectral Analysis of voltage source and the convenient Power Factor according to the section (2.2) and using simulations under MATLAB/Simulink.

Using the Matlab functions as: (FFT) to determine the spectrum of a signal, (Mean) for the average value of the instantaneous power due deduct the active power, (Fourier) for the average value and the voltage and phase angle of the fundamental current and (THD) for the harmonic distortion of voltage and current, respectively.

2.3.1. Spectral Analysis

Four cases are studied in this section, to view the effect of the distortion form of the voltage source v(t) and the nonlinear charge.

$$v(t) = 311\sin(100\pi t) + 50\sin(300\pi t) + 30\sin(500\pi t) \qquad (4)$$

First case: Using a sinusoidal source and resistive charge 10Ω

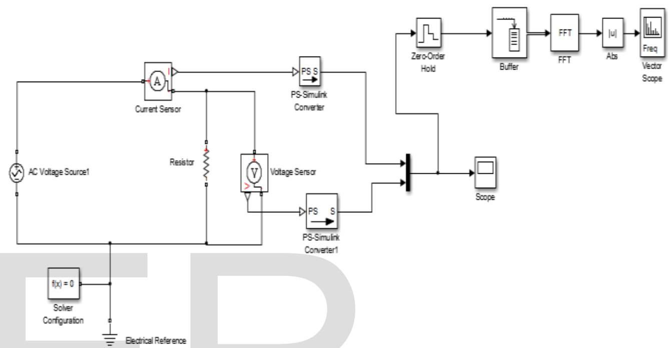


Figure 5: Simulation diagram

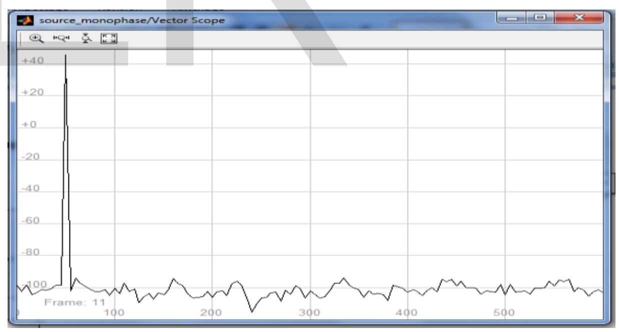


Figure 6: Spectral analysis

2nd ***case:*** Using a no sinusoidal source and a resistive charge 10Ω

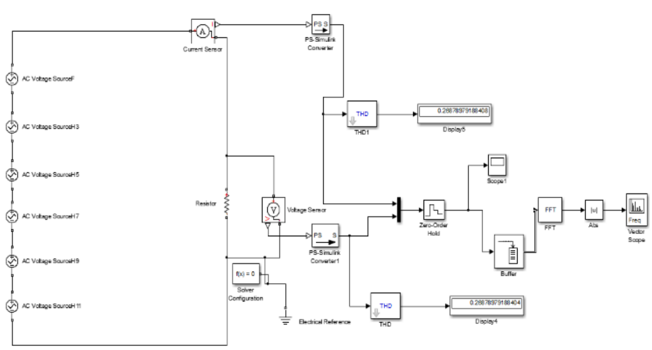


Figure 7: Simulation diagram

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

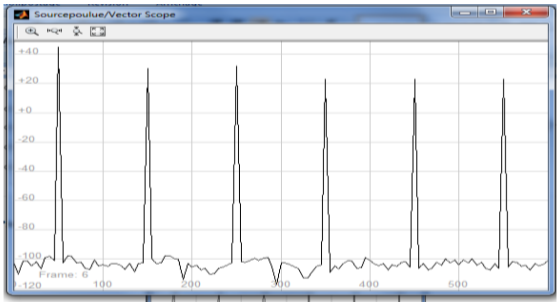


Figure 8: Spectral analysis

3rd case: Using a sinusoidal source and a nonlinear charge

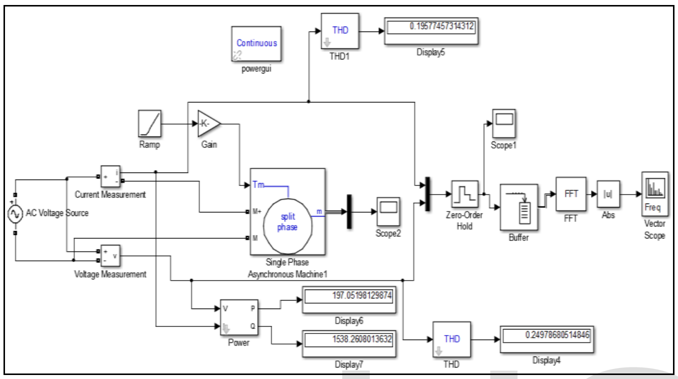


Figure 9: Simulink diagram

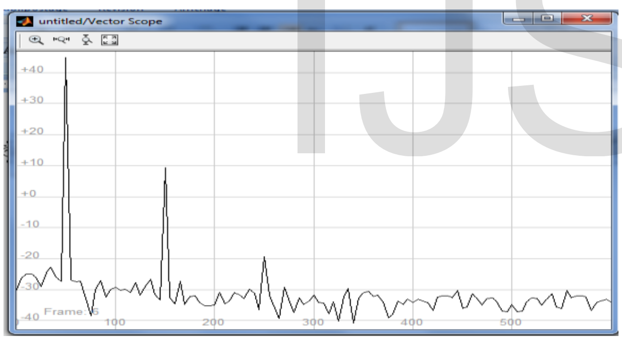


Figure 10: Spectral analysis

4th case: Using a no sinusoidal source and a nonlinear charge

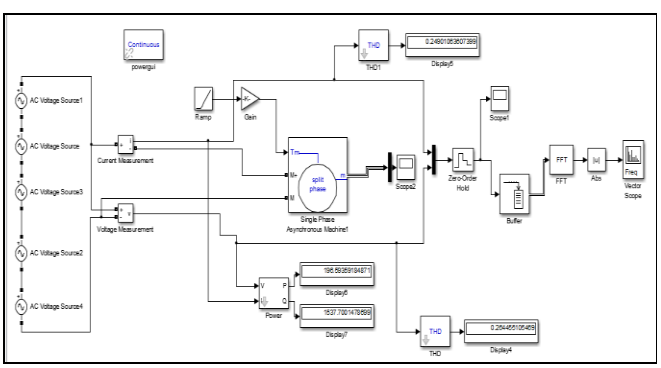


Figure 11: Simulation diagram

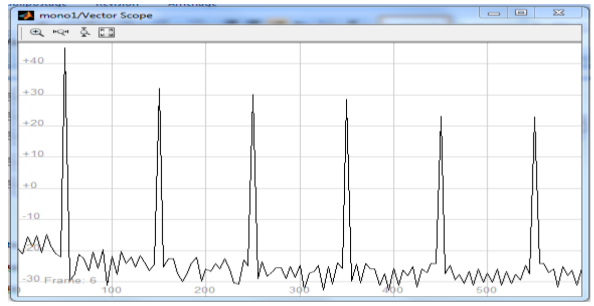


Figure 12: Spectral Analysis

2.3.2. Simulations Results

To sum up the simulation results of the power factor computation for the four cases, a table 2 is presented below.

TABLE 2. SUMMARY OF THE SIMULATIONS RESULTS

	Sinusoidal Voltage source		*No Sinusoidal Voltage source*	
	Linear charge	*Non Linear charge*	*Linear charge*	*Non Linear charge*
P(W)	4990	104.6	5239	105
S1(VA)	-	108.2	5300	104
S(VA)	4990	111.3	5309	107
Cos θ	1	0.9947	1	0.9995
FP	1	0.9401	0.9869	0.9815

3 NETWORK ANALYZER CONCEPTION

The network analyzer consist: Firstly, to receive and read the network current and voltage. Secondly, it conditions the signals and transmits them to the microprocessor. This µprocessor traits the information and transmits them to PC and to the LCD display.

3.1. Signal Conditioning

First of all, a current and tension transformers are used to receive analogic signals. A rectifier without threshold is used in this case. Its principles of operation consists to:
The waves of a sinusoidal AC input voltage $v_e(t)$ are adjusted: When $v_e(t) > 0$, the current $i(t)$ is positive since $V\_ = 0$, only D_1 can ensure it. The inverter circuit with the branch that contains D_1, V_s negative and $V\_$ being nil. D_2 is blocked. Conversely, when $v_e(t) < 0$, D_2 is leading to $i(t) < 0$, and D_1 is blocked.

The diodes are ideal (without conduction threshold), alternating positive and negative half. Subtracting the two voltages $V_2 - V_1$ leads to full-wave rectification $v_e(t)$ of either:

$$V_s(t) = A\left| v_e(t) \right| \quad \text{with } A = 10 \qquad (5)$$

Using the PSIM software, the Mounting scheme of the studied rectifier is established and is presented using fig.13.

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

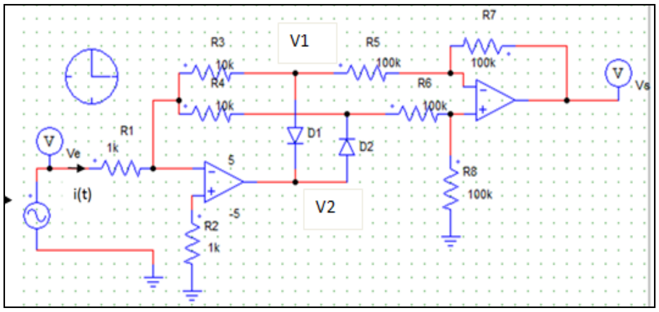


Figure 13: PSIM mounting of the rectifier without threshold

The AD736 amplifier is used to read the RMS voltage and current values, see fig. 14. These values are, then displayed on the LCD screen and they are used for calculating the power factor, see fig. 15.

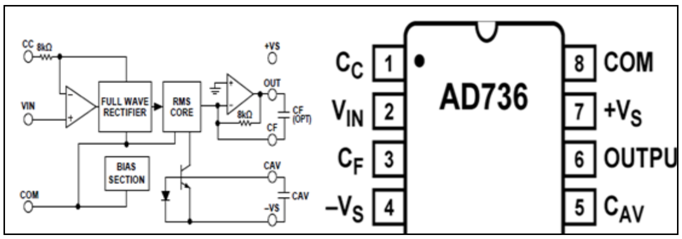


Figure14: AD736 Internal Architecture [12]

The AD736 amplifier deliver a very small RMS value that is between 0 and 200mV. Therefore, it is necessary to amplify before it is converted to the analog input of dsPIC.
So, to amplify the output of the AD736, the no inverter assembly to basic LM358 amplifier is used, see fig.11. The RS232 module is used to be connected to PC.

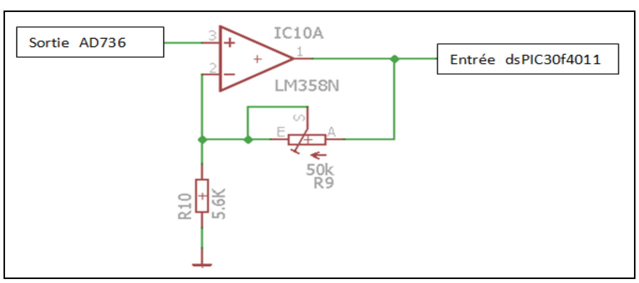


Figure 15: AD736 Output amplification

4 Hardware Design

A development card DsPICDEM2 is used to include the dsPIC30F family and permits the demonstration and the development for different dsPIC. It includes all the necessary modules for the DSP operation, like the voltage corrector, UART and its adaptor, Connector, Debug, LED's, Switch's.

The choice is fixed on the dsPIC30F4011 for this application. This micro-Controller is a 16 bytes processor and it includes a DSP (Digital Signal Processor) treatment unit, see fig. 16.

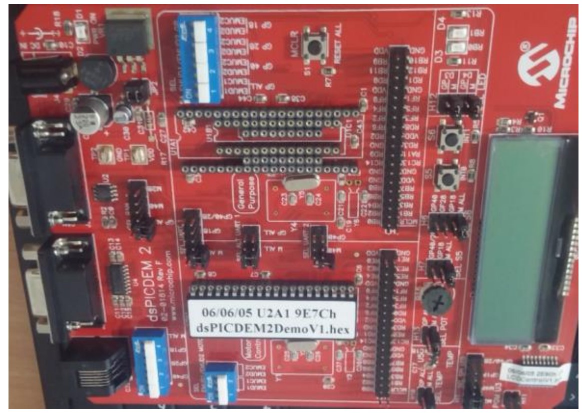


Figure 16: The dsPICDEM™2 card

This card provides 9 A/D 10-bit (500ksps) canals, tow UART, one SPI module, one I2C module, one CAN module and 30 I/O broches, see fig.17.

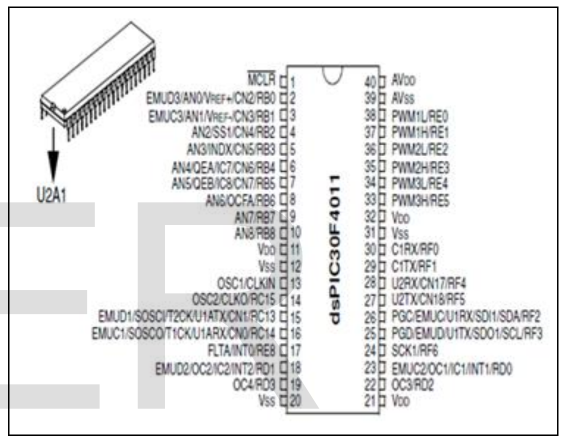
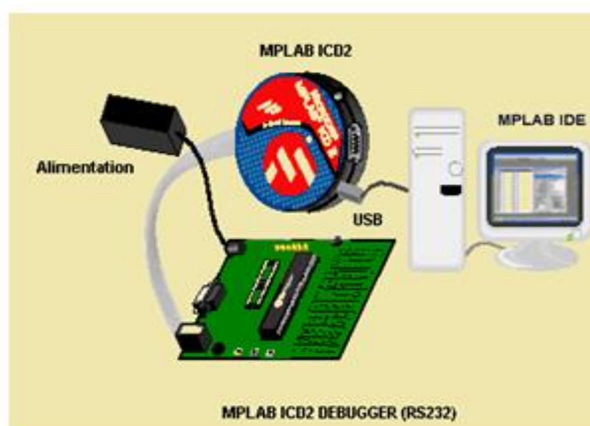


Figure 17: dsPIC 30F4011 [13]

The development is done under MPLAB IDE and an ICD 2 is used to write the program memory of the micro-controller.



(a)

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

(b)

Figure 18: (a) , (b) MPLAB ICD2 configuration

The acquisition card is developed to achieve the FFT treatment under the DSPICDEM card. An input signal from the dsPICWorks and a display of the harmonic frequencies using LCD display and the RMS values of the voltage and current signals.

To supply the PIC card, 5V is applied. 12V is applied for the relays and the buzzer. The montage is designed under Eagle software to read the V_{RMS} and V_H. Fig. 19 presents the corresponding power scheme.

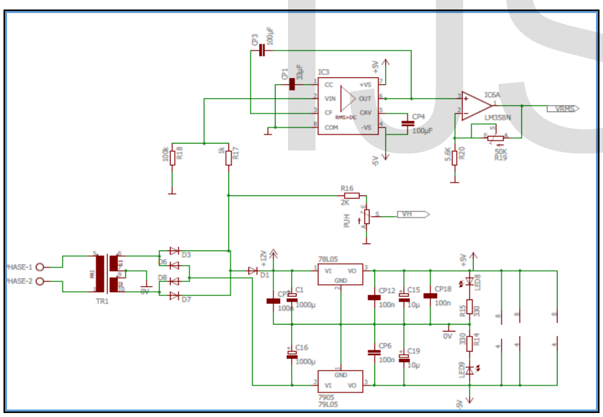


Figure 19: Power Scheme, RMS voltage and harmonic voltage

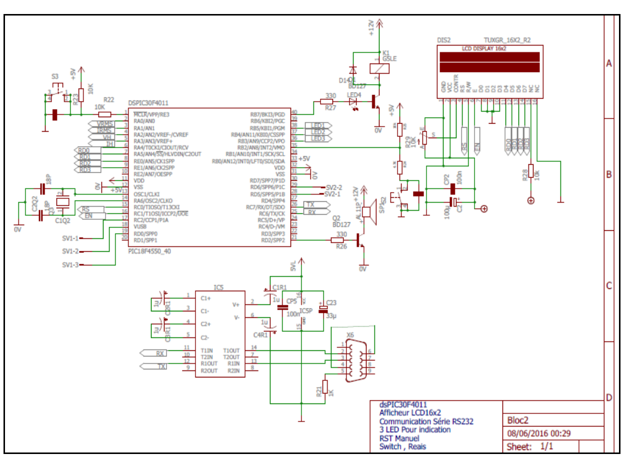


Figure 20: Display Scheme, RS232, Buzzer relay and dsPIC30F4011

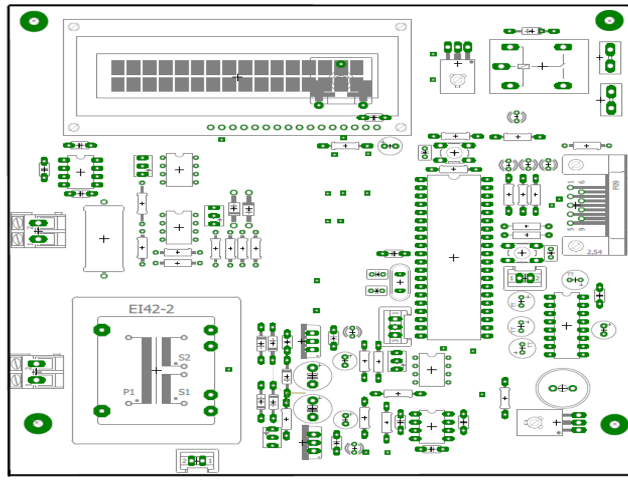


Figure 21: The routing scheme viewed from the components side

5 Experimental Test and Evaluation

When Dspicworks generate an input signal, the FFT processing procedure provides the required frequencies on the LCD. A square wave is generated under DsPicworks as an input signal. It's converted to a C code and then injected in the program. The VectorMax() function returns the higher spectral indices frequency. These frequencies are displayed on the LCD, see fig. 22 and 23.

The RMS values of the current and voltage are readden using pins 5 and 6. The harmonic voltage and current are readden using pins 2 and 3, these parameters are then stored on a complex vector, see fig. 24.

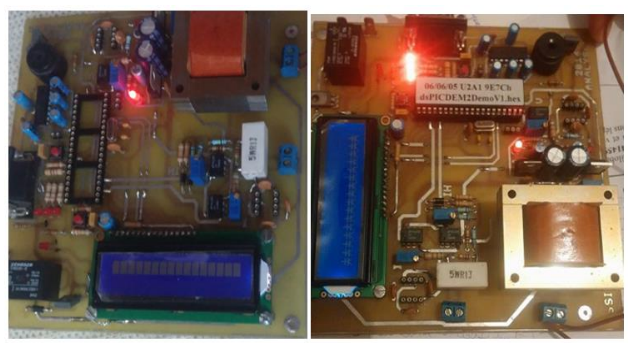


Figure 22: Card test

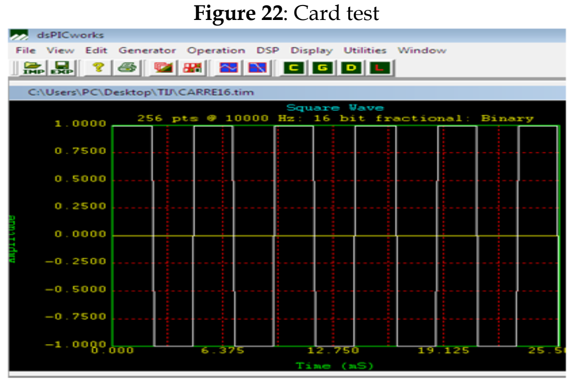


Figure 23: The input signal as square wave

International Journal of Scientific & Engineering Research, Volume 8, Issue 9, September-2017
ISSN 2229-5518

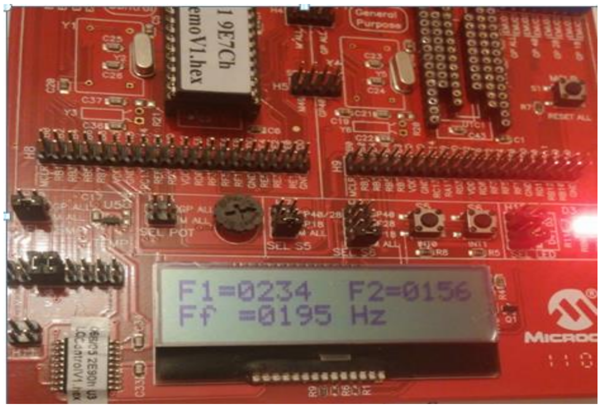


Figure 24: Frequencies display as an output of the DSPICDEM card

6 Conclusion

In this paper, an electric network analyzer is designed and is implemented under a DSPICDEM card. Firstly, numerical modeling and simulation of the FFT analysis is studied under MATLAB/Simulink. Secondly, an experimental prototype is designed using the dsPICs. Its tested to follow the FFT analysis results and it deals to calculate the real power factor.

These network quality problems can cause dysfunctions with serious consequences and excessive energy costs. Hence, the need for electrical power analyzer allows protecting themselves by ensuring the quality of the delivered energy.

Acknowledgments

The Global Energy Renewable Society has supported current development and investigation.

References

[1] Wildi, T. Sybille, G.: 'Electrotechnique', 4th edition, printed on Canada.
[2] Sio-Hum Jo, Seoeun Son, Jung-Wook Park, 'On improving distorsion power quality index in distributed power grids, *IEEE transactions on smart grid* , vol.4, N°1, march 2013
[3] Reidla, M. and al., 'TMS320F28335-Based high accuracy complex network analyzer instrument', *5th European DSP education and research conference,* 2012.
[4] Site web, Chauvin-Arnoux, http://www.conrad.fr, accessed at 24/05/2016.
[5] EN 50160, « Caractéristiques de la tension fournie par les réseaux publics de distribution », Février 2011. https://fr.scribd.com/doc/138394325/NF-EN-50160-pdf, Accessed: April. 15, 2016.
[6] Sourabh Jagadale Dipankar De , V Ramanarayanan, 'An inexpensive digital network analyzer', *35th Annual Conference of IEEE Industrial Electronics,* 2009.
[7] A. V. Oppenheim, R. W. Schafer, Discrete Time Signal Processing, *Pearson Edition,* 2003
[8] Perez E., Barros, J.:'Voltage Event Detection and Characterization Methods: A Comparative Study', IEEE PSE transmission and distribution conference and exposition, Venezuela, 2006.
[9] Ingale, R.: '*Harmonic Analysis Using FFT and STFT*', Department of Electrical Engineering, V.D.F. School of Engineering and Technology, Latur, India.
[10] Datasheet AD736, http://www.alldatasheet.com/Ad736
[11] dsPICDEMtm2 development Board user's guide, *2015 Microchip technology.*
[12] 'Fundamentals of Network Analysis Feb 11, 2016, http://www.ni.com/white-paper/11640/en/, accessed 23 Mars 2017
[13] S. Levy, H. Matzner, 'Experiment 1- Network Analyzer', 4 Jully 2004, http://www.hit.ac.il, accessed 23 mars 2017.
[14] Si-Hun Jo, SeoEun So, Jung-Wook Park, 'On Improving Distortion Power Quality Index in Distributed Power Grids', *IEEE transactions on smart grid,* vol. 4, no. 1, march 2013
[15] Leon M. Tolbert, Harold D. Hollis, Peyton S. Hale, 'Survey of harmonics measurements in electrical distribution systems', *Industry Applications Conference,* 1996. Thirty-First IAS Annual Meeting, IAS '96.
[16] Antony C. Parsons, W. Mack Grady, Edward J.Powers, John C. Soward, 'A Direction Finder for Power Quality Disturbances Based Upon Disturbance Power and Energy', *IEEE/PES and 8th International Conference On Harmonics And Quality of Power Proceedings,* Greece, October 1998.
[17] G. Miramontes de Leon, F. Gomez Aguilera, E. Garcia Dominguez, 'A dsp56002-based frequency response network analyzer', *14th International Conference on Electronics, Communications and Computers, CONIELECOMP* 2004.
[18] Cristina, Gherasim, Alfredo Ortiz, Jeroen Van den Keybus, 'Implementation and comparison of power definitions using a DSP based prototyping system', *11th International Conference on Harmonics and Quality of Power,* 2004.
[19] Alexandra A. Carniato, Ruben B. Godoy, Joao Onofre P. Pinto, 'Development of hardware and software for three phase power quality disturbances detection, classification and diagnostics using Kalman filter theory', *IEEE* 2009.
[20] Drazen Jurisic, Neven Mijat, Miro Ranilovic, 'Power consumption, noise and bode diagrams measurement of active filters, *MOPRO* 2011, May 23-27, Opatija, Croatia.
[21] Manoj Badoni, Alka Singh, Bhim Singh, 'DSP Based implementation of an immune feedback algorithm for control of shunt compensator', *IEEE* 2016.