PC-BASED MEASUREMENT OF REACTIVE CURRENT AND VAr UNDER NON-SINUSOIDAL CONDITIONS

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Abstract - *This paper deals with the problem of measuring reactive power in energy systems under nonsinusoidal conditions. The time-domain approach due to Fryze, which has now gained wide acceptance, is adopted for defining VAr under such conditions. A simple PC-based equipment for measuring reactive power is described. The system facilitates expeditious determination of all relevant variables involved, and the computation of the active and reactive components of current with respect to voltage. A simple, low cost hard ware circuit has been developed for generating the sampling frequency from the input voltage of arbitrary wave shape. The software used for carrying out the various mathematical operations is then presented. Results of measurements made on typical non-sinusoidal waveforms are given. The results are compared with those obtained from theoretical calculations.*

Keywords – VAr measurement, nonsinusoidal, PC-environment

1. INTRODUCTION

When a nonlinear load is excited by a sinusoidal or nonsinusoidal voltage, the resulting current may contain in addition to frequency components that are present in the exciting voltage, some additional frequencies that are generated due to the load nonlinearity. Switched-mode power supplies, inverters, arc furnaces and welding machines are instances where we have to deal with nonsinusoidal voltages and currents. A knowledge of reactive power under such circumstances will enable us to partially compensate for the same, using reactive elements like capacitors and inductors, leading to substantial increase in efficiency.

2. FRYZE´S DEFINITION AND ASSOCIATED RELATIONSHIPS

While the concepts of true power P and reactive power (*VAr*) Q are well defined for sinusoids of a single frequency, the definition of *VAr* under non-sinusoidal conditions has been long debated upon. Both the frequency domain and time-domain approaches have been put forward [1-3]. It appears to be meaningful to adopt the definition due to Fryze[4], in which the component of the load current that has a waveform identical to that of the voltage, is rightfully called the *active* component. Whatever remains after subtraction of this active component from the load current is to be regarded as *reactive*, without bothering about whether reciprocation of energy is involved or not.

If $v(t)$ and $i(t)$ are respectively the non-sinusoidal voltage and current in a load, we have:

$$\mathrm{P} = \frac{1}{\mathrm{T}} \int_0^{\mathrm{T}} v.i.dt \tag{1}$$

If R is a pure resistance that would consume this P with the given non-sinusoidal voltage of effective value V applied across it, then

$$R = \frac{V^2}{\mathrm{P}} = \frac{\int_0^{\mathrm{T}} |v|^2 .dt}{\int_0^{\mathrm{T}} v.i.dt} \tag{2}$$

The active and reactive components of current are:

$i_a = \frac{1}{\mathrm{R}} \; v(t)$ and

$i_r = i - i_a$.

Acceptance of Fryze's definition for Q as $\sqrt{\mathrm{S}^2 - \mathrm{P}^2}$ leads to the relationship

$I^2 = I_a^2 + I_r^2$

among the three components of the load current.

Accordingly, Q = $V.I_r$.

Analog and digital systems have been reported for measuring Q and S with nonsinusoidal voltages and currents[4, 5].

3. DESCRIPTION OF THE MEASURING SCHEME

3.1 Block diagram of the scheme

The block diagram of the measurement scheme is given in Fig. 1.

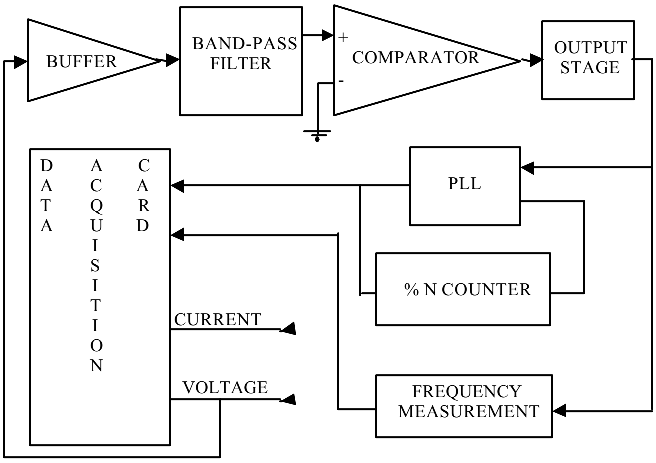

Fig. 1 Block Diagram of the hardware

Appropriate voltage signals representing the system voltage and current waveforms are made available at the analog input channels of a 12-bit A/D converter which forms the front end of the Data Acquisition Card (PCL 818HG in the present case). The card also contains an 8254 programmable timer-counter (counters 0, 1 and 2), the counters in which are used for pacer-triggering and frequency measurement. An external hardware circuit generates the sampling frequency, which is 200 times the fundamental frequency. The A/D converter samples the voltage for a time equal to one complete period of the voltage waveform, starting from zero. The current-samples are taken in the next cycle, starting from the instant of zero-crossing of the voltage. By virtue of the periodicity of two waveforms, this arrangement corresponds to simultaneous sampling of the current and voltage. At the input to the Data Acquisition Card, 200 samples of the voltage are received first, followed by 200 current-samples. The software converts the digitized voltage and current samples from integer to floating point format and estimates all the relevant parameters and waveforms. The output waveforms can be viewed in Matlab.

3.2 Hardware generation of sampling frequency

Fig. 2 shows the hardware blocks used for sampling frequency generation.

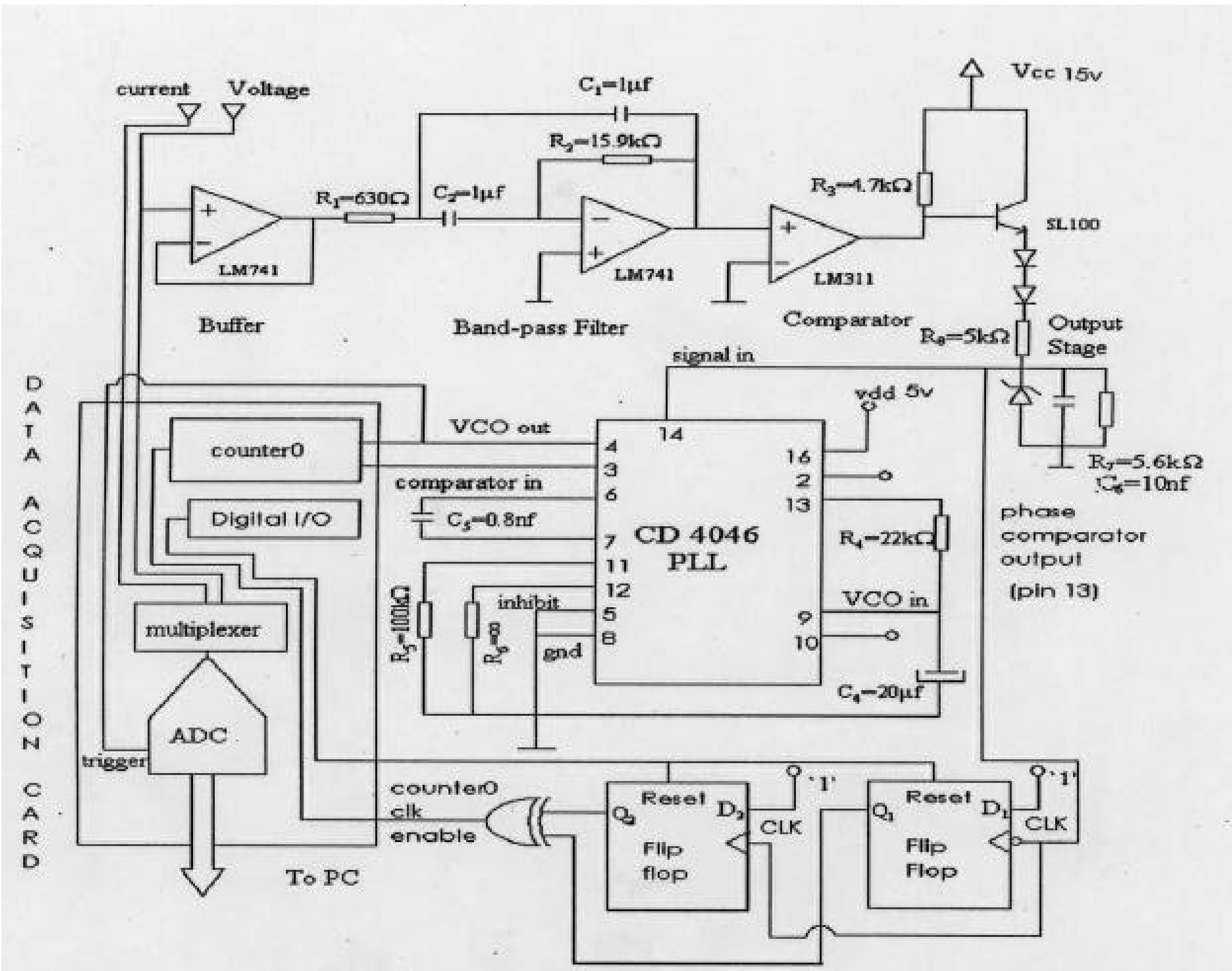

Fig. 2 Hardware for generation of sampling frequency

The input voltage waveform is given to a band pass filter whose output is a sine wave of fundamental frequency of the voltage and current waveforms. The sinusoid is converted into a square waveform of the same frequency using a comparator circuit. The output stage of the comparator feeds a PLL (Phase-Locked Loop), which acts as a frequency multiplier and generates the sampling frequency. The comparator output also facilitates the measurement of the fundamental frequency using two D-flip-flops and an XOR-gate, the latter enabling Counter 0 of the 8254 for exactly one half-period of the input waveform.

3.3 Software adopted

The integration-expressions appearing in (1) and (2) are carried out in digital domain, operating on the output sequences coming from the A/D converter. The software adopted is straightforward and uses an assembly language program embedded in a C-program environment. The flowchart for data acquisition is shown in Fig. 3. The software first enables external triggering and then sets the A/D converter range and trigger mode. As mentioned earlier, the first 200 samples correspond to the quantized voltage and the next 200 to the current. Software polling is used for data transfer from the A/D.

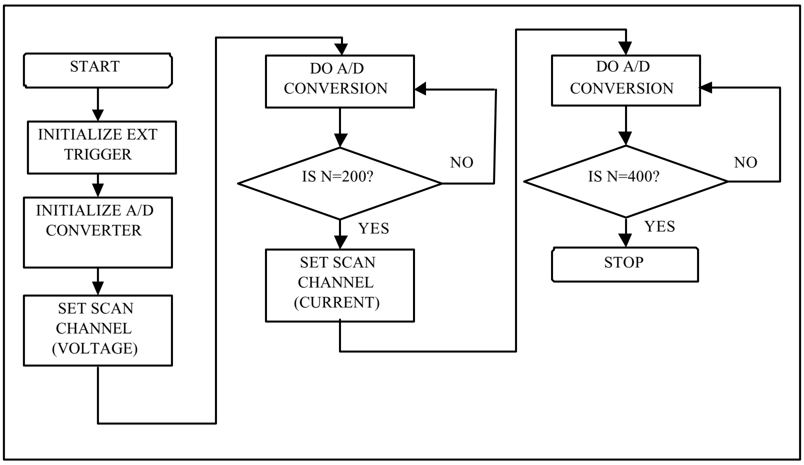

Fig. 3 Flowchart for data acquisition

4. EXPERIMENTAL RESULTS

Tests were conducted in the Laboratory, using voltages and currents of the following wave-shape combinations, without and with phase-shift between the two:

- both being sinusoidal,
- both being square or triangular and
- voltage being square and current triangular.

Waveform Generator HP33120A has been used in twin-oscillator configuration to generate the different waveform-combinations, the desired phase-shift being set through menu-commands. The experimental results are given in Table1, along with theoretically computed values of Q and S for a few waveform combinations. The discrepancy between the theoretical and experimental values is of the order of two percent in most of the cases. When the voltage and current have the same wave shape with no time phase difference, the reactive power should be ideally zero and i_q completely absent. In the measurements carried out, i_q was observed to be a high-frequency waveform of very low amplitude, independent of the wave shapes of the voltage (and current). Fig. 4 depicts the voltage, current and the active and reactive components of the latter for a *square-triangular* combination.

Table 1: Comparison of experimental results and theoretical calculations

Peak values of the voltages corresponding to v and i = 2V

Wave shape		Phase difference as function of cycle	I_a		I_q		Q		S	
$v(t)$	$i(t)$		Expected	Theoretical	Expected	Theoretical	Expected	Theoretical	$\sqrt{P^2+Q^2}$	$V*I$
Sine	Sine	$\frac{1}{12}$	1.248	1.225	0.668	0.707	0.95	1.0	2.01	2.01
Square	Square	$\frac{1}{12}$	1.327	1.333	1.511	1.491	3.03	2.98	4.03	4.03
Square	Triangular	Nil	1.0	1.0	0.582	0.578	1.156	1.1677	2.32	2.32
Triangular	Triangular	Nil	1.166	1.155	0.024	0.0	0.028	0.0	1.89	1.89

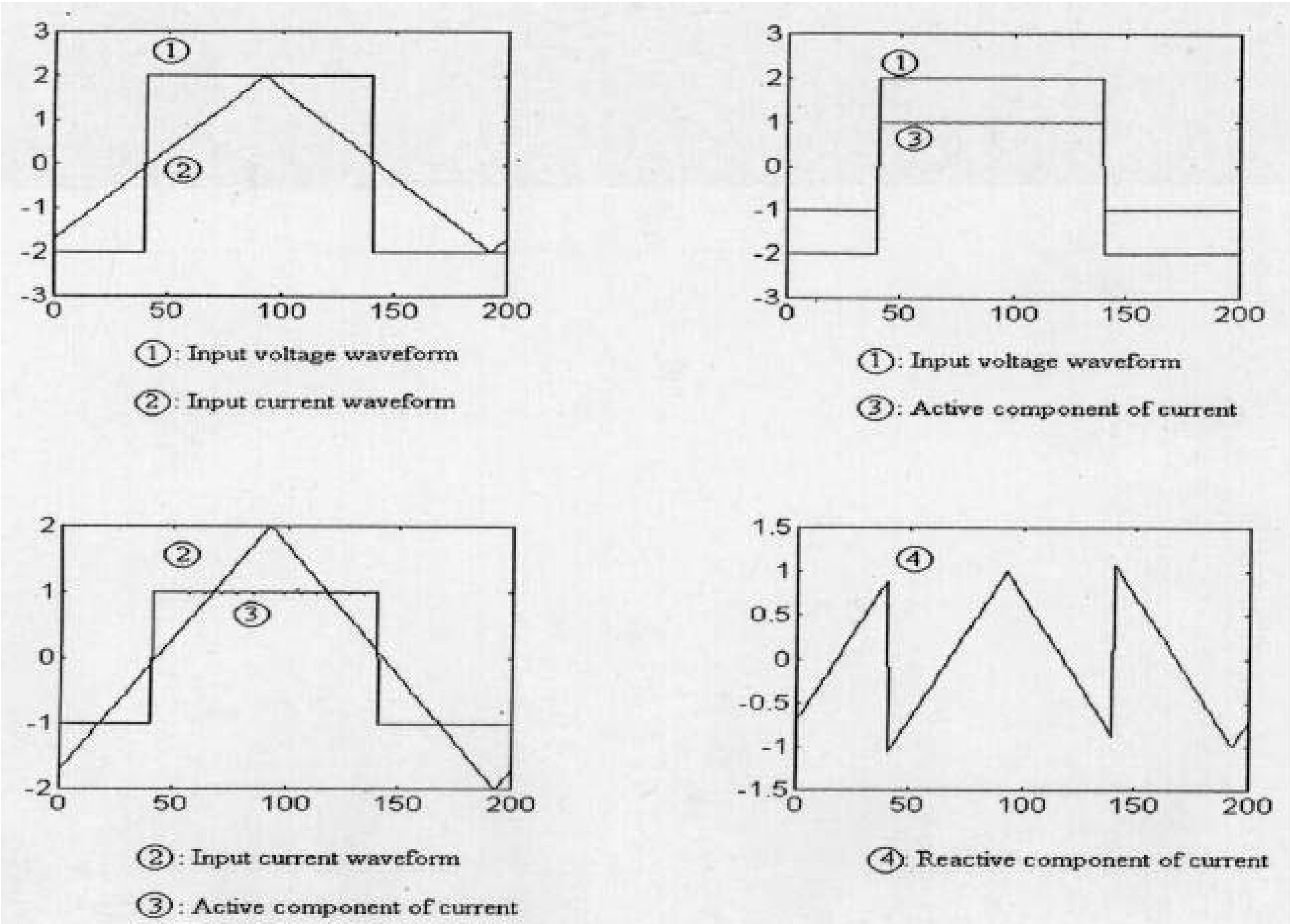

Fig. 4 Active and reactive components of current with square wave voltage and triangular wave current

5. CONCLUSION

In this paper, a PC-based instrument designed and constructed for the measurement of Fryze's reactive power under nonsinusoidal conditions has been described. The set-up reported has been tested with different typical wave-shape combinations of voltage and current. The test results are found to be in good agreement with those arrived at from theoretical calculations. The scheme is easily extendable to three-phase systems, using the three-element principle.

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