A PC-based three-phase system analyser

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Abstract

As the use of power electronics and inductive loads on electrical supplies increases, the requirement to monitor power system quality becomes an increasingly common practice. The negative effects these loads have on supply balance and frequency can be reflected in the efficiency, and therefore the running costs, of said loads. With demand for analysis techniques in industry increasing, and the PC becoming a more popular tool for such applications, a low-cost PC-based electrical system analyser was proposed to demonstrate a cost-effective, accurate alternative to the expensive market-leading products. This study researches the problem at hand, the technology available, and the development and testing of the analyser in a laboratory environment.

The success of this study was determined by the accuracy, cost, functionality and features of the analyser compared with those of an existing product. The final product was to be a virtual instrument (VI) PC application implemented using the industry-leading LabVIEW software package by National Instruments. Two major challenges of the study were the correct measurement of the fundamental voltage and current waveforms, and the appropriate/accurate reconstruction, manipulation and display of these signals within the software. Identification, and minimisation or correction, of measurement errors was an important factor in achieving maximum accuracy prior to software interpretation of the data.

Testing and calibration were carried out with the aim of providing the most accurate signal measurement prior to data acquisition and rescaling by the software program. Industry-standard design and manufacture techniques were implemented to produce a high-quality hardware package featuring a printed circuit board, ingress protection (IP) rated enclosure and screened multicore signal cabling.

The potential uses and benefits of the analyser include monitoring loads in factory floor or manufacturing environments where production costs are of significant importance; in this instance, multiple analysers could be in place over the floor to aid operators. Smaller companies using smaller amounts of large machinery may implement a PC-based system as a cheaper alternative to an expensive all-in-one unit.

The study concluded that a reasonably accurate PC-based analyser could be produced on a small budget; it also highlighted the many advantages of a PC-based system in terms of usability, customisation and flexibility. A critical evaluation of the system's performance compared to a benchmark model and further suggestions for improvement are included.

Keywords: Three-phase; power system analyser; LabVIEW; power quality.

Introduction

The study aimed to produce an analyser system capable of accurately investigating and monitoring a commercial-type (three-wire or three-phase) electrical supply. The analyser would be PC based and the end product would be in the form of a virtual instrument (VI); the emerging use of VI has allowed for increased development of more cost-effective alternatives to traditionally expensive products.

Objectives:

- Create a hardware circuit consisting of measurement electronics and signal conditioning, creating data suitable for acquisition by PC. The hardware should be enclosed to prevent contact with electrical connections and damage; industry-standard connections and design/manufacturing techniques should be used.
- Manipulate data using the software package and create professional and user-friendly VI displaying key electrical characteristics such as voltage, current, power and energy consumption, as well as their respective visual representations (waveform diagrams, etc.).
- Produce an overall package that could be left to monitor a system for a long period of time in a safe manner, i.e. low heat generation and efficient software design.

The software package implemented was LabVIEW by National Instruments, a market-leading graphical programming environment with a wide range of analytical functions.

Background research and literature review

Power analysers are typically standalone pieces of equipment that measure the fundamental components of an electrical system and provide quality-based figures such as power, energy and power factor; these parameters can help to diagnose poor-quality supplies and problematic loads due to phenomena such as unbalance or interference. These devices aim to be minimally intrusive to the supply and the operation of the connected load, and therefore use sensor-based measurement techniques with a dedicated power supply. The role of the PC was to allow the analyser to be used as an application, i.e. used alongside other programs and left to monitor or record the data of interest.

Measurement technique

The analyser required measurement of the system current and voltage, which would be scaled down to a range suited to the data acquisition (DAQ) card installed in the PC, ±10 volts analogue. From the various techniques considered, the most cost effective and widely available was the Hall-effect transducer, which is available in voltage-measuring and current-measuring versions.

The Hall effect, named after Edwin Hall, who discovered the phenomenon in 1879, essentially applies a magnetic field at a right angle to the current flowing through a conductor; this generates a small voltage across the conductor. The discovery of the Hall effect, as stated by Ramsden (2006), followed from Ampere’s observation of the mechanical force exerted on a current-carrying wire when it was placed in a magnetic field; this led Hall to investigate whether it was the wire itself or the current flowing in the wires that the force was acting upon. Hall discovered that the force on the current caused it to concentrate to one side of the wire, thus creating the small measurable voltage across the wire.

Both the voltage and current transducers selected use the same principle of operation; however, the current transducer uses the carrying conductor as the primary winding and is non-intrusive to the supply, and the voltage transducer measures between the line and neutral conductors using physical connections to an internal primary conductor. Closed-loop technology (essentially incorporating a type of feedback loop) was preferred to open-loop as it provides better accuracy and linearity, and eliminates output drift caused by temperature changes (a feature of some open-loop transducers).

Power system quality

Power system quality has been the subject of many articles, regulations and guidelines aimed at both consumers and energy providers with the aim of conserving the quality of supply for themselves and other users. According to the Institute of Electrical and Electronics Engineers Std. 1159 (IEEE, 2009), the term ‘power quality’ references a wide variety of electromagnetic phenomena that comprise the current and voltage at a given time and location on a power system. The installation of a suitable power analyser on a system would allow the detection, investigation and recording of said common phenomena outlined by the IEEE standard. These are as follows.

<u>Transients</u>

These are events affecting the power system that are undesirable and momentary in nature, further grouped into two categories:

- Impulsive transients – sudden, non-power frequency changes in the condition of voltage and/or current that are unidirectional in polarity, that is, either negative or positive, typically defined by their rise and decay times. Lightning is the most common cause of impulsive transients.
- Oscillatory transients – sudden, non-power frequency changes in the condition of voltage and/or current that are bidirectional in polarity and that change rapidly between positive and negative. Predominantly frequency based, they are defined by magnitude, duration and spectral content.

<u>Short-duration variations</u>

Short-duration variations in voltage are most commonly caused by fault conditions, starting conditions of large loads, or intermittent connections in power wiring due to loose or broken terminals or contactors. Depending on location and system conditions, these faults can cause temporary effects such as voltage swells and sags, or even complete interruption of supply (loss of voltage).

- Momentary and temporary interruptions – when the supply voltage or load current is reduced to less than 0.1 per unit (pu) (where 1pu is the nominal value for the signal of reference, 0.5pu would be half that value) for a period of time less than 1 minute.
- Sags (dips) – a reduction in voltage between 0.1pu and 0.9pu for durations from half a cycle to 1 minute. Often the magnitudes of sag are quantified using percentages, for example 20% sag, which refers to a sag creating a voltage of 0.2pu (or 20% of the original magnitude). Sags are usually associated with system faults and the switching of heavy loads.
- Swells – an increase in voltage above 1.1pu to 1.2pu for durations from half a cycle to 1 minute. Swell magnitude, as with sag magnitude, is quantified by its remaining voltage and will always be greater than 1.0pu. Swells are less common than sags and can be caused by single line-to-ground faults that cause swells on the remaining active phases, switching off a large load, load shedding or switching on a large capacitor bank.

Long-duration variations

These refer to deviations of power frequencies lasting longer than 1 minute; they can be either over-voltages or under-voltages that are generally not the result of system faults. They can be caused by load variations on the system as well as switching operations.

- Over-voltage – an increase in AC voltage of between 1.1pu and 1.2pu for longer than 1 minute. Poor voltage regulation and incorrect transformer tap settings can be causes of over-voltage.
- Under-voltage – a reduction in voltage of between 0.8pu and 0.9pu for longer than 1 minute. Over-loaded circuits, switching of capacitor banks and switching on loads can cause under-voltage.

Supply imbalance

Imbalance (or unbalance) in a three-phase system is described by IEEE Std. 1159 (2009) as the ratio of the magnitude of the negative sequence component to the magnitude of the positive sequence component in either a voltage or a current, expressed as a percentage. The typical voltage imbalance of a three-phase supply is less than 3%; however, the current imbalance can be considerably higher.

Voltage imbalance is calculated using the following equation:

$$\%\, Imbalance = \frac{Vneg}{Vpos} \times 100\%$$

A summary of terms according to IEEE Std.1159 can be seen in Table 1.

Table 1: IEEE Std. 1159 Summary of Terms

IEEE Std. 1159	**Term of Variation**	**Definition**
1.	Interruption	Voltage below 10% of nominal magnitude
2.	Momentary interruption	Duration of 0.5 cycles to 3 seconds
3.	Temporary interruption	Duration of 3 seconds to 1 minute
4.	Sustained interruption	Duration of 1 minute upwards

Harmonics

The underlying frequencies of an analogue signal are called harmonics or harmonic components. The cause of a distorted signal can often be traced to its harmonics, a signal whose frequency is an integral multiple of the fundamental frequency. The higher the harmonic order, the smaller the amplitude of the signal and the less impact it has in terms of distortion during sampling. The amplitude can be determined by dividing the amplitude of the fundamental frequency (x) by the harmonic order (n):

$$amplitude\ of\ n^{th}\ harmonic = \frac{x}{n}$$

In relation to voltage and current signals, Wildi (2006) outlines magnetic saturation in transformer cores and switching of electronics in motor drives and inverters as the main causes of harmonic signals. In power circuit signals, often the voltages have acceptable sine wave structure, but the current signals can be distorted. Power electronics that use switching devices produce distorted waveforms that can contain considerable harmonic distortion.

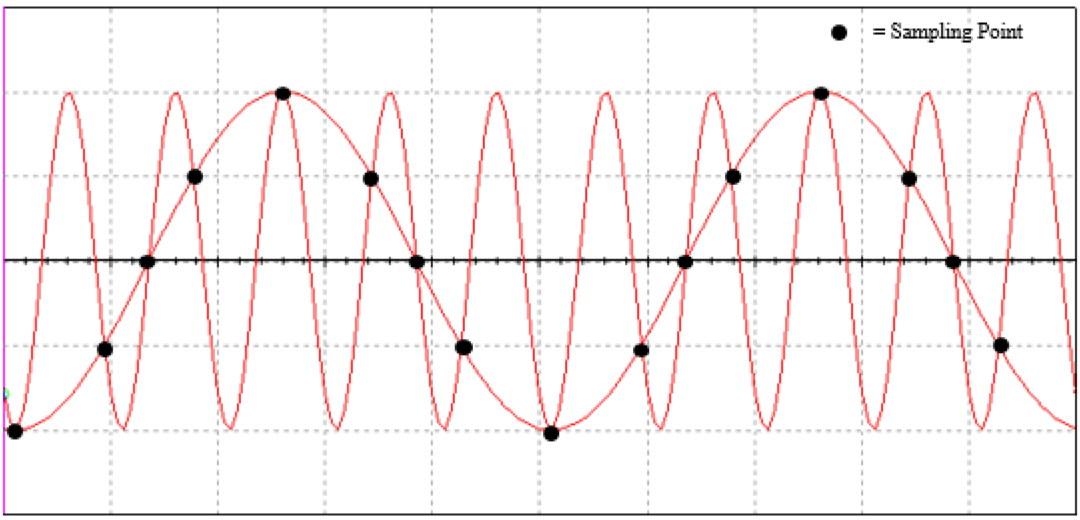
Today's power systems are most likely to be affected by quality problems generated at consumer level. Harmonic distortion is an example of such problems and is generated by power electronic devices (as previously discussed), variable-speed drives/inverters, uninterruptable power supplies, fluorescent lighting and computers, all of which employ switching of the supply. Inductive loads such as air conditioning units and induction motors, back-up power supplies and improper grounding are also causes of harmonics. The harmonics of a waveform can be determined by the overall wave-shape: if the sine wave has identical negative and positive half cycles then it is said to have half-wave symmetry and will only contain odd harmonics (3, 5, 7, 9, etc., when referring to the Fourier series examination of harmonics). This is normally the case with currents and voltages in power systems such as this application. Total harmonic distortion (THD) is the most utilised method of identifying harmonic content of a distorted waveform. It is defined as the root mean square (rms) of the harmonics and is expressed as a percentage of the fundamental component (i.e. mains frequency 50Hz) (Masoum & Fuchs, 2015).

Aliasing and filtering

It was proposed that the analyser incorporate anti-aliasing filters prior to data acquisition in order to ensure that waveforms were being sampled free from noise and as accurately as possible. These filters attenuate signals outside of the desired frequency range to prevent the sampling system measuring such interference and affecting the software reconstruction of the 50Hz sinusoidal wave.

The effect on analogue signals known as aliasing refers to the way in which said signals are sampled and reconstructed. The common example, as used by Maxim Integrated (2002), is the filming of a wheel by a low frame-rate camera that cannot capture the accurate speed and direction of the wheel as its speed increases, giving the impression that the wheel is turning in reverse. When referred to a sine wave, the low sampling rate of a DAQ card can recreate inaccurate signals due to the same problem of capturing signal samples too slowly. Figure 1 demonstrates how the frequency of a 50Hz sinusoidal signal can be under-sampled.

Figure 1

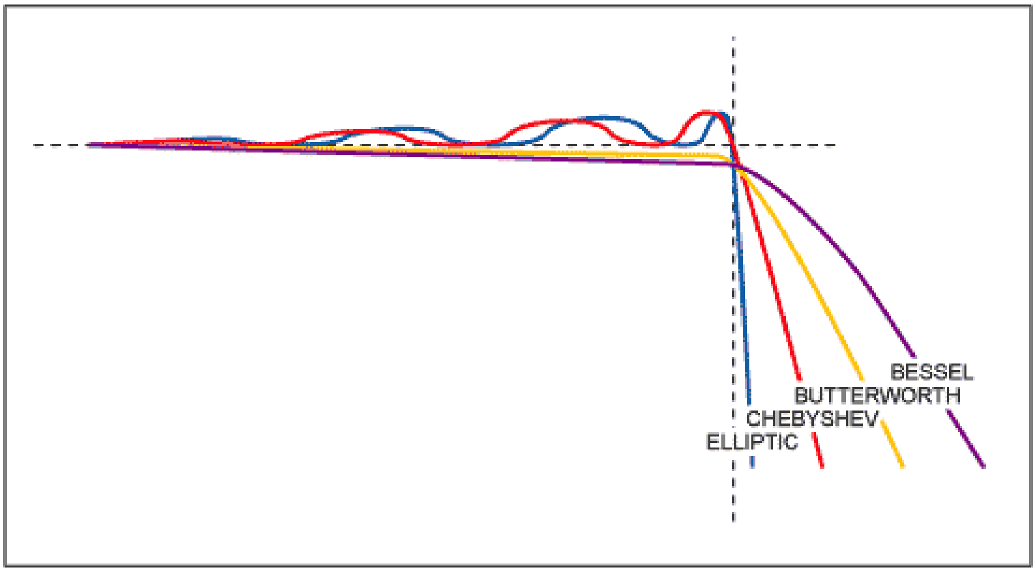


To avoid this under-sampling, the Nyquist sampling limit is a well-practised method that ensures that a signal is properly measured and reconstructed. It states that a signal should be sampled at a minimum of twice its own frequency, but often, in practice, it is usually higher, to reduce the filtering requirements and provide a more detailed measurement of the signal if possible.

Anti-alias filters are commonly low-pass filter circuits that precede analogue-to-digital converters (ADCs) and remove or significantly attenuate the unwanted frequencies/noise from a signal to provide an undisturbed input to a measurement device.

Different filter types are defined by their pass-band gain and roll-off characteristics. This application required a pass-band gain of one (unity), in order to maintain the accuracy of the measurement, and a reasonably steep roll-off. Referring to the research material, in particular Figure 2, it was clear that the filter design most appropriate was the Butterworth type, as it met both of the requirements outlined.

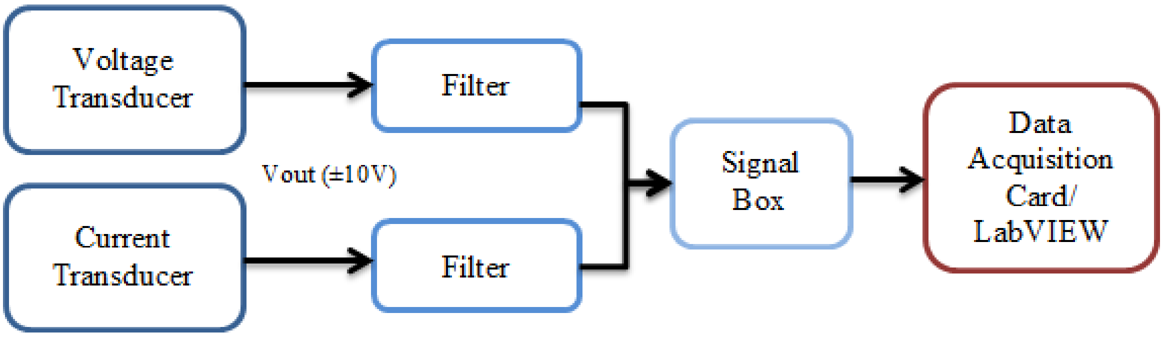
Figure 2



Methods and procedures

Testing was performed in stages throughout the analyser build, with the electronic elements tested individually and then combined before being connected to the PC for the software development. Figure 3 shows the block diagram, individual elements and signal path of the analyser system.

Figure 3



The final analyser was tested on a 5.5A, 220V-rated AC induction motor, giving a per-phase voltage of 127V (rms), which was specified as the upper per-phase measurement value (before headroom) of the analyser electronics.

Measurement electronics

The input to the DAQ card installed in the PC was limited to ±10V analogue range and it was therefore important to ensure that the signal produced by the measurement transducers fell within this range to prevent damage to the acquisition card. The transducers selected provided output in the milli-ampere (mA) range, leading to the use of measurement resistors (Rm) to provide a suitable voltage range when measured between the output pin and 0V. Similarly, the input to the voltage transducer needed limiting to 10mA maximum, again requiring an input resistor (Rin) limiting the current and meeting the required specification.

Simple Ohm's Law calculations determined the resistor sizing.

<u>Voltage transducer LEM LV25-P</u>

Applying a 20% headroom to the values as good practice:

$$Vline = \frac{Vsupply}{\sqrt{3}} = \frac{220}{\sqrt{3}} = 127V$$

$$20\%\ headroom, Vmax = 127 * 1.2 = 152.4V$$

To ensure that the 10mA input limit was not exceeded and there was some margin above normal operation for any possible error voltage readings, the value of Rin was selected such that the headroom voltage would provide a 7mA input to the transducer:

$$Rin = \frac{Vmax}{Ipri} = \frac{152.4}{0.007} = 21771.42\Omega \approx 22k\Omega\ nearest\ common\ value$$

The upper and lower limits of measurement resistor Rm were stated on the LV25-P datasheet as 100Ω min. and 190Ω max. (for ±15V supply). In order to obtain a voltage output that used a reasonable amount of the ±10V output resolution at normal operation, the upper most common value of 180Ω was used. The peak–peak voltage output of the transducer at 127VAC was therefore:

$$Vout = \frac{Vin}{Rin} * conversion\ ratio * Rm * \sqrt{2} = \frac{127}{22k} * 2.5 * 180 * \sqrt{2} = \pm 5.19Vpp$$

Current transducer LA55-P

Only a measurement resistor was required for the current transducer because there is no physical connection to the device; the current-carrying conductor passes through the device acting as a primary coil and the magnetic field is measured within.

Similar to the voltage transducer, the Rm value for the current transducer was selected to give good use of the output range and be under the ±10V peak (7Vrms) limit at normal operation. This was checked using the formula:

$$Vout = \frac{Ipri * no.of\ primary\ turns}{Conversion\ Ratio} * Rm$$

$$= \frac{5.5 * 3}{1000} * 270\Omega = 4.45Vrms = 6.3Vpk$$

This value of Rm exceeds the maximum value recommended on the LA55-P datasheet; in doing so, the maximum measuring current of the transducer was reduced to under the 50A rating. For this application, which measured between 0 and 10A (rms) maximum, it was not a concerning factor.

The use of more than one primary turn allowed for a higher output current with respect to the input current; multiplying the input current by the number of primary turns is known as the ampere-turns rule. This rule is demonstrated in this case by the secondary-to-primary conversion ratio of the device, which was 1:1000 for one turn and 3:1000 for three turns. For example, one ampere through three primary turns creates a magnetic field strength equivalent to a 3A primary current, which is then measured by the transducer as such. This method also reduced the maximum measuring current; however, its use is common practice when using transducers or current transformers at lower than rated current in order to obtain higher output measurements and use more of the transducers' measurement range.

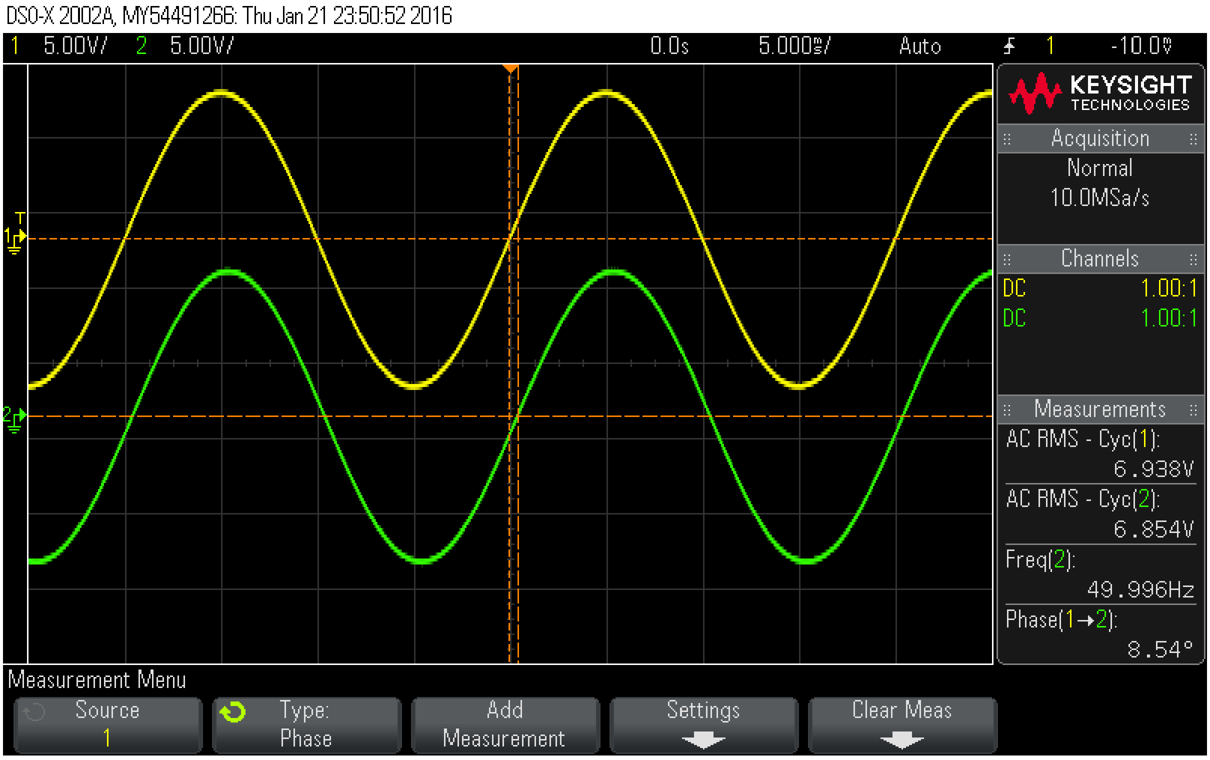
Filter design

Design of the filter was aided by an online software tool offered by Texas Instruments. Once the filter topology that was the best identified by the research had been selected and a commonly available Op-Amp IC chosen, the software selected the passive component values that would provide the best response. The software allowed the user to compromise filter sensitivity for more common passive values, thus keeping the cost of materials low. Simulated response of the filter allowed for useful comparison during the testing phase of the prototype and final circuit design.

The filter was tested using a 50Hz sinusoidal signal input from a function generator to simulate an AC electrical supply signal; a digital oscilloscope was used to compare the input and output waveforms.

Figure 4 shows the filter tested at the fundamental frequency of an electrical signal; the oscilloscope shows the gain was 0.987 and phase shift 8.54°.

Figure 4



Electronics test

It was important to test the electronic circuits together for linearity in the measurement range and verify the accuracy of the signals before they were sampled by the PC software. Providing the error between the measured supply voltage and current (provided by a multi-meter connected prior to the system electronics) was found to be relatively consistent throughout the range, adjustments could be made during the scaling process of the software design to compensate for the error. The main causes of error in the electronic part of the system were the use of passive electronic components and slight inaccuracies in the power supplies connected to the operational amplifiers and transducers. Accuracy of the current transducer is reduced due to the increase of primary turns in place contributing to higher core losses (LEM International, 2004).

Taking into account the theoretical outputs of the devices, the total errors through the measurement and filtering circuits were:

- Voltage-measuring circuit: ±4.98%
- Current-measuring circuit: ±8.49%

Once the prototype circuits had been tested, the final circuit board design was completed using EagleCAD drawing software to produce a printed circuit board (PCB) onto which the through-hole components were soldered. The board was mounted in an enclosure to provide physical protection from the electrical terminals, and connections for double insulated leads were fitted. Figures 5 and 6 show these features.

Figure 5

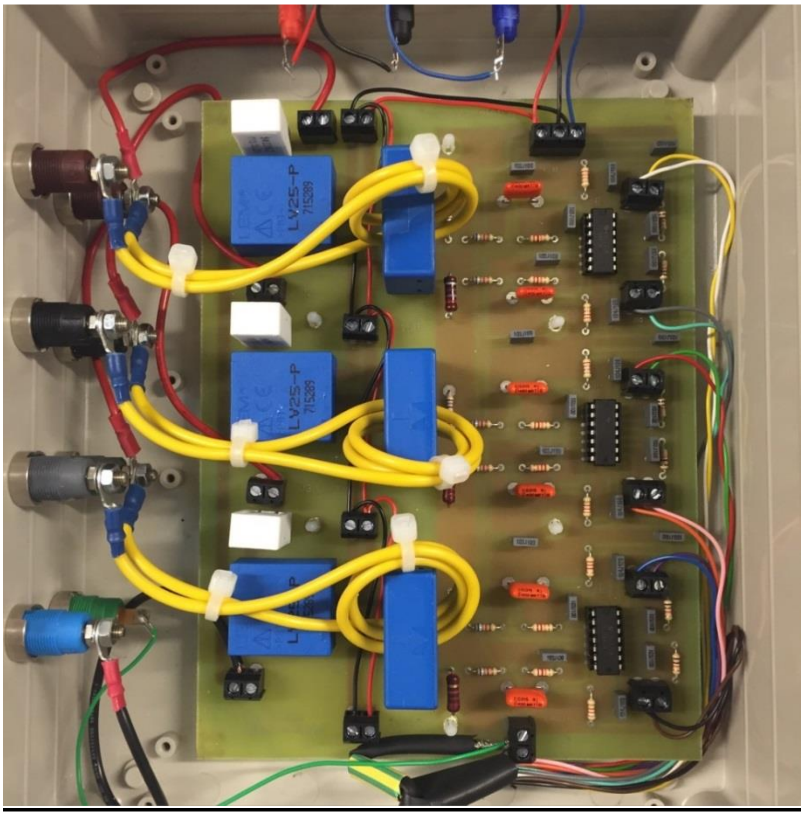


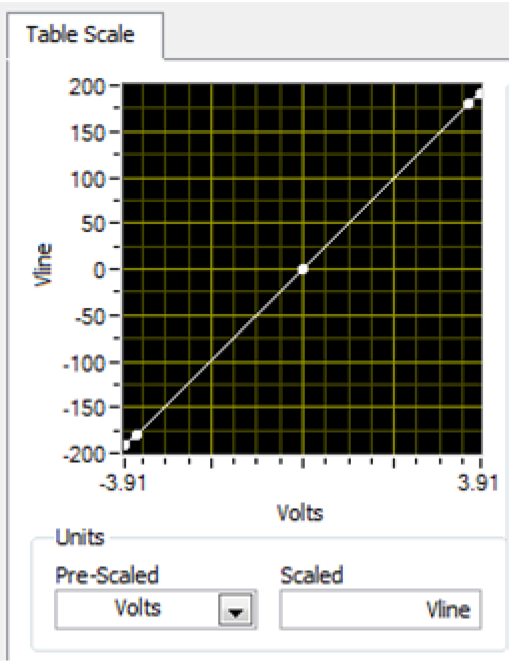
Figure 6

Software and VI

Scaling

Signals acquired by the PC were scaled down by the transducers to meet the requirement of the DAQ card. Therefore, in order to accurately recreate and display the actual amplitudes, appropriate up-scaling needed to be applied. With the LabVIEW software package it was possible to acquire and scale the signals within an ‘express’ function block. Scaling the signals required a certain level of calibration to be performed; recording the voltage at the nearest point prior to the PC acquisition with an oscilloscope for the range of the mains supply established a scale that could be entered into a table within the software, which produced a linear scale (Figure 7), applied as the data is sampled.

Figure 7



Software development

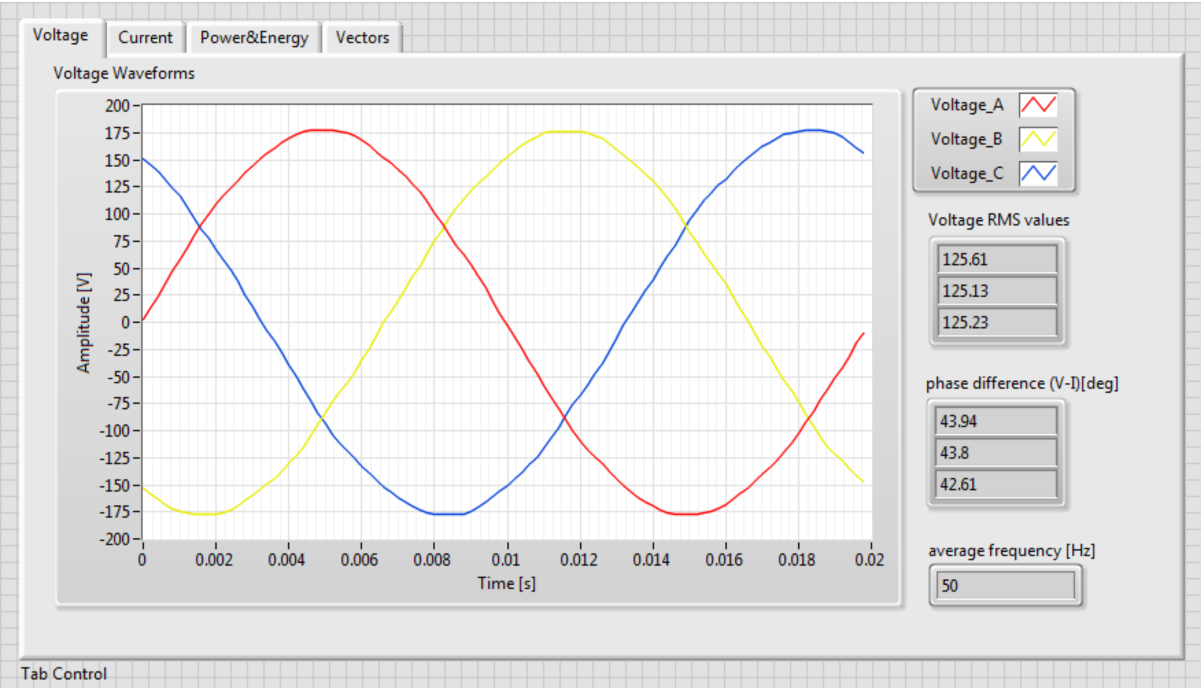
Building the software program was a gradual process that began with displaying the voltage and current sine waves and numerical values on the front panel VI; from that point, this information could be manipulated to produce values of power and energy. There were three derivatives of the software block diagram as a greater understanding of the LabVIEW package was achieved. A basic display of the fundamental values was followed by a more comprehensive VI, including power and frequency, concluding with a comprehensive block diagram producing total power, energy consumed, unbalance and the ability to estimate cost per usage. The program implemented function blocks inclusive of the Electrical Power Suite section of LabVIEW, but also displayed information that required extracting from bulk data arrays and use of mathematical blocks to produce final or summed values. Understanding of different data types within the block diagram and conversion between types was a crucial learning curve to create a flowing system with useful features.

The final iteration of the system block diagram employed the use of a ‘Task’ in place of the DAQ Assistant block which converts the express block into its alternative block code. A ‘while loop’ and timer delay were used to keep the acquisition and various functions operating; the delay kept the front panel graphics (waveform graphs and numeric indicators) displaying steady and easy-to-read figures as they updated at a recognisable speed.

Front panel

The final judgement of the analyser was on the appearance and usability of the front panel VI created in LabVIEW. As the name suggests, it should allow the user to view measurements and figures as they would on an oscilloscope or multi-meter. The front panel needed to be clear and easy to use, with colour-coordinated waveforms, legends and indicator labels. To prevent a cluttered screen and to allow the user to select the information they wished to view, the tab function was used to move between voltage (shown in Figure 8), current, power and energy, and vector diagrams. The aim was to produce a VI that can be both monitored and read at a glance, and used for thorough system analysis.

Figure 8



Results

Results in terms of measurement accuracy were compared with an advanced three-phase analyser produced by Yokogawa that was connected to the same electrical supply and load for a direct comparison throughout the development and testing stages. Use of the Yokogawa model proved that the measurement electronics and software were measuring and displaying accurate values and wave-shapes. Results were recorded across the range of the motor connected to the supply by varying voltage and load torque.

Measurement comparison

Table 2 shows the tabulated results for both analysers when the motor was drawing full-load current at rated voltage. Hardware measurements of voltage and current were acceptably similar. The software-based measurements of power and power factor were varied, with total power 6% higher than that of the benchmark Yokogawa, and power factor almost equal.

Table 2: Comparison of Measurements - Full-Load Current

127V/Phase (FL)	System	Phase A	Phase B	Phase C	Total	Difference (LBA-Yokogawa)	Difference as % of Yokogawa Value
Voltage [Vrms]	Yokogawa	125.44	124.68	124.99	216.57	0.497	0.229
	LBA	125.61	125.13	125.23	217.07		
Current [Irms]	Yokogawa	5.525	5.408	5.466	5.466	0.211	3.854
	LBA	5.62	5.67	5.74	5.677		
Average Frequency [Hz]	Yokogawa	49.996				0.004	0.008
	LBA	50					
Total Power [W]	Yokogawa	1462.4				87.080	5.955
	LBA	1549.48					
Power Factor	Yokogawa	0.7132				0.007	0.953
	LBA	0.72					

Across all the results taken, the voltage and current measured by the transducers and filtering circuits showed very good accuracy when compared to the Yokogawa analyser. As these two parameters were the basis of the calculations within the software for power and energy values, it was determined that the larger differences in power values between the two systems was due to the differing calculation methods. This was further reinforced by examining the way the power function block within the software used the data to produce a value of power.

Display comparison

Figure 9 shows a side-by-side comparison of the current waveforms measured and displayed by both analysers; due to the characteristics of the load connected, the waveform was distorted, especially at the peaks. A clear similarity could be seen between the two displayed signals, proving that the hardware electronics and software were working accurately to produce results comparable with the industry-assured Yokogawa model. The close similarity between the wave-shapes validated the selection of a 5kHz sampling rate as the detail of the waveform distortion was also of an acceptable quality.

Figure 9

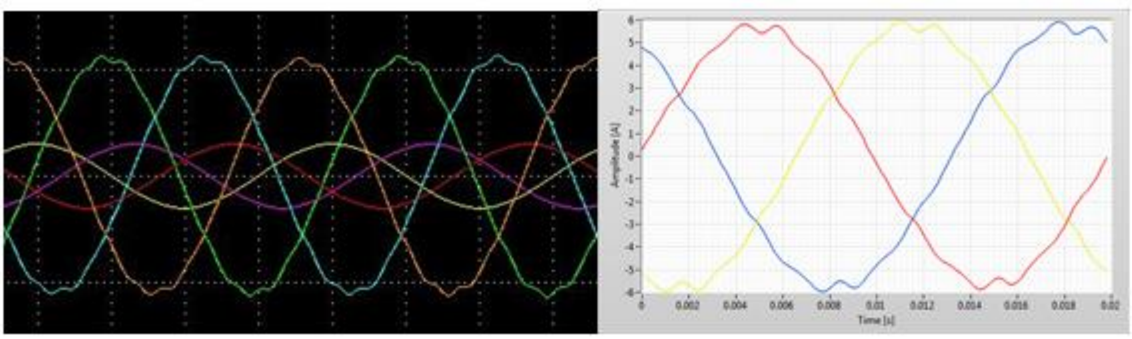
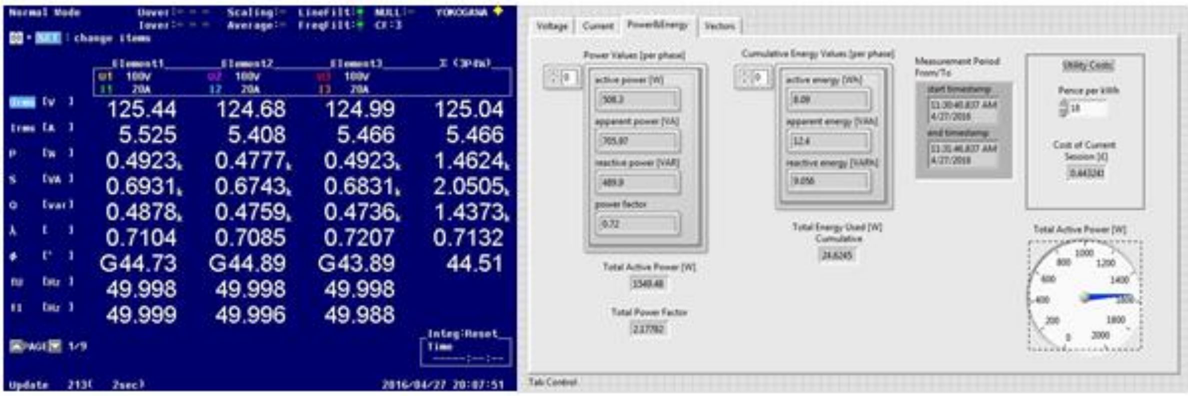


Figure 10 shows the contrasting displays of the analysers. This highlights the flexibility of PC-based applications: their ability to be customised means that the VI can be designed to display all the information relevant to the user and even to implement status or warning indicators. Figure 10 features the power and energy information tab from the LabVIEW software, which focused on power and energy consumption as well as power factor and cost estimation. Numerical and graphical indicators were used to provide specific and at-a-glance data, respectively.

Figure 10



These analyser displays cannot be directly compared as they have largely different applications. The LabVIEW-based analyser was designed for use in small monitoring, recording or setup applications, to name a few, and therefore requires a more user-friendly, softer-looking display than the industrial, clinical appearance of the more portable Yokogawa unit.

Discussion

The success of this study was due to the appropriate allocation of time: a good balance between research, development and testing provided a solid understanding of the chosen measurement principle and functionality of the hardware. Extra time and care taken designing the PCB meant that the board was manufactured fault-free first time; this was important, as the board was large and mistakes would have increased the final cost of the analyser. Managing the hardware stage properly ensured that when the software stage began, there was confidence in the acquisition data, and progression of software development could be carried out without changes to the hardware, producing minimum delays.

The hardware consisted of good-quality transducers, within the budget allocated, and reasonable order filtering to deliver the signals to the PC. The combined circuitry produced small percentage errors when tested across a broad supply range. One area of improvement, had time permitted, would have been further tuning of the filter networks, as the passive components produced a small phase shift that is thought to have contributed to the differing power values of the analysers.

With regard to the accuracy of the system, from the comparison in Table 2, the largest discrepancy between the analysers was the value of total active power. This difference varied at approximately the same rate that the power itself increased from test to test; the difference in the values displayed could have been down to the way the analysers calculate the power. From studying the Yokogawa readings, it was determined that the active power values displayed were exactly equal to:

$$Power\ per\ Phase[W] = Vn(rms)\ \times In(rms)\ \times \cos(\theta n)$$

where *n* is the phase of interest and θ is the phase angle between the respective voltage and current. However, the power function block within the LabVIEW library takes the voltage and current waveforms, multiplies them together, finds the resulting waveform component and takes the mean average of the data values. These different methods of power calculation could have been a contributing factor in the differences in active power values, as could the phase shift from the anti-aliasing filter and the measurement accuracy of the transducers. With data being passed through the system and manipulated to produce other parameters, it is always possible that small errors at the measurement stage will be amplified to slightly larger errors further on in the system.

The software aspect of the analyser showed good use of both the purpose-made function blocks from the Electrical Power Suite add-on, express functions and assistants such as DAQ Assistant, and also the ability to break down the grouped signals and manipulate them to produce singular, totalled or averaged values to be displayed. Aesthetically speaking, the VI front panel was set out clearly with a standard colour scheme, which is important when the design of human machine interface (HMI) systems is considered. If this PC-based system were to be used as a permanent supply-monitoring system in a production environment, a minimal number of visual changes would be required. In terms of user customisation, there are areas that could be improved, such as the ability to adjust the waveform graph scales as easily as the Yokogawa model allows. An additional tab providing an overview of the main system parameters may also have been a useful feature, allowing the user to view numeric values of voltage, current, power and energy at one glance if desired. In the time frame allocated for software development, it was not possible to fully explore all the functions offered by LabVIEW, some of which are highlighted in the future works section of this article.

Build costs for the analyser came in at under £200, mainly due to the use of materials already available, such as the filter components and PCB board; voltage transducers purchased at approximately £40 each and an enclosure costing £25 were the highest costs incurred. Current transducers were already available for use, but even if all materials used had been purchased, the total cost would still have been under £300. There were no areas identified where a clear cost saving could have been made. A hidden cost of using an analyser of this type is the initial purchase of the LabVIEW software package licence from National Instruments; this comes at a significant cost, but does still outweigh the cost of a current, high-specification power analyser such as the Yokogawa model featured in this report. The cost of the software package would have less impact if multiple analysers were desired, as the cost could be spread across the multiple units.

Conclusion

The methodical design approach of this study and the focus on producing a professional final product with a specific target market resulted in a well-rounded and capable PC-based analyser. The performance and accuracy of this analyser is respectable when compared to the technology, development and investment from which the benchmark Yokogawa system will have benefited. In terms of application, this PC-based system could be used in low- to mid-accuracy-dependent environments such as education or small manufacturing sectors. With some improvements and developments identified throughout this body of work, and discussed in the following section, the system could be used reliably over a large factory floor, providing power and energy information continuously for a fraction of the cost of some existing systems.

Future work

This investigation has much more to offer in terms of software programming features; LabVIEW offers a wide range of possibilities and methods to manipulate data. Front panel enhancements that would improve the system could be the ability to easily adjust the time and amplitude scale on the waveform graph using button icons similar to those on a digital oscilloscope. Addition of an extra viewing tab to display an overview of all major measurements may also be a useful feature for monitoring purposes.

An extra feature of LabVIEW Electrical Power Suite is the ability to look at harmonic content, a subject covered in the initial research section of the paper, which can be the root cause of some major supply interruptions and quality issues. The ability to view harmonic and spectral content would be a major advantage of a PC-based system over a system such as the Yokogawa model used for comparison data.

A significant advantage of implementing a PC in modern analyser systems is the ability to record, revisit and send data easily and efficiently. Data recording is a feature that could easily be implemented on this LabVIEW system to take it further towards being a more complete competitor of more established systems and achieve the potential of a PC-based system.

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