A Future User Interface for the Fluke Power Quality Analyzer

The Design of Job Assistance Features and Touch Screen Functionality for Power Factor Analysis

Bachelor Thesis
Philip Jansen
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Philip Jansen
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University of Twente
Faculty of Engineering Technology
Industrial Design Engineering

Post office box 217
7500 AE Enschede
The Netherlands

Benchmark Electronics B.V.

Lelyweg 10
7602 EA Almelo
The Netherlands

Chairman of the exam committee
prof.dr.ir. A. de Boer

Mentor at University of Twente
ir. A.P. van den Beukel

Mentor at Benchmark Electronics
C.P. Suurmeijer, BA

Preface

Carrying out this project at Benchmark Almelo has been a unique and valuable learning experience. The people I was around were always very kind to me and the atmosphere was excellent. I really have had a most memorable time.

While I have enjoyed the company environment, there would be little truth in saying things went smooth process-wise. Getting familiar with the subject matter was anything but easy: I have found it difficult to get a good grasp of the abstract concepts that comprise power quality, power factor and user interface design. Moreover, this project confronted me with the fact that I am an awful planner. I have spent far too much time in the orientation phase, wasting it by delving deep into topics that were essentially of lesser relevance. I did not have a good perspective on the project for most of the time.

As anyone reading it entirely may probably notice, I was in a bit of a hurry to finish the report. The quality of many sections, especially the latter ones, is not as I would have wished. On a positive note, however, I am quite satisfied with the final design concept I have created. There is much to improve upon, but in the end I think I have made a meaningful contribution to Benchmark and Fluke.

I would like to thank everyone who provided me with assistance throughout this project. In particular, I wish to thank the following people:

Christian Suurmeijer, for offering his guidance and support throughout the project, and for his cheerfulness and encouraging words.

Maarten van Alphen, for sharing his knowledge and expertise, and for often being available at a moment’s notice.

Arie Paul van den Beukel, for offering his guidance and advice, and for having considerable patience with me.

Contents

1 Introduction

In this era of electric power liberalization and energy conservation efforts, the concept of "power quality" is becoming increasingly important. Electronic test tools manufacturer Fluke Corporation creates sophisticated portable instruments that can measure the quality of electric power in power distribution systems. Power Quality Analyzers, as they are called, are used by electric engineers to troubleshoot power problems and maintain power systems at industrial, office and public locations.

Fluke is a market leader and strives to maintain its position through innovation. On behalf of Fluke, contract manufacturer Benchmark Electronics, is searching for new design concepts for a future Power Quality Analyzer's *user interface*. Benchmark would like to see a future user interface support comprehensive "job assistance" features that make the user's work tasks less demanding, more efficient and more convenient. These job assistance features should primarily be aimed at making the instrument more accessible to blue-collar electrical technicians. Benchmark reasons that with an enriched target user group, Fluke will be able to sell more Analyzers.

In addition, Benchmark wishes the design to feature touch screen functionality. Some of Fluke's competitors already use it in their products. The benefits of using touch screen technology include larger screen sizes, higher durability, and generally more usable interfaces. Furthermore, touch screen technology could help facilitate the deployment of job assistance features.

To limit the scope of this project the user interface should be specifically devised for *power factor analysis.* Power factor is an indicator of the efficiency of a power distribution system. Many businesses deal with power distribution systems that have low power factors, and are incurring significant financial losses as a result. Power factor analysis is an important aspect in reducing the cost of energy of these businesses. Benchmark regards it as an excellent vehicle to showcase a user interface's support of job assistance features with.

The goal of this project is to aid Benchmark in its development of future Power Quality Analyzers for Fluke, by creating and evaluating a design concept of a novel, *more user-friendly* user interface for a future Power Quality Analyzer. This user interface should (1) support comprehensive job assistance features that help electrical technicians in performing power factor analyses, (2) have touch screen controls and (3) be economically feasible five years from now. The concept is to offer useful insights for further development of user interfaces that support comprehensive job assistance features and touch screen controls.

The report will begin with a rather lengthy discussion in chapter 2 of important concepts relating to Fluke's Power Quality Analyzers, power quality and power factor. This will culminate into a problem description in chapter 3. Subsequently, chapter 4 will discuss job assistance ideas, the user's work practice and the present user interface, while chapter 5 will describe the basic preconditions that apply to any solution of the problem. The requirements specification will be presented in chapter 6. Chapter 7 will detail the design concepts and chapter 8 will discuss the final design concept. In chapter 9 the design will be evaluated by comparing it to the requirements specification. Project conclusions recommendations will be provided in chapter 10.

2 Background

The sophistication nature of the Power Quality Analyzer and the complicated concepts that relate to it, necessitate the discussion of a fair bit of background information before a proper description of the assignment's problem can be given. In this chapter Fluke Corporation and its products will be introduced; the Power Quality Analyzer and concepts of *power quality* will be discussed; and the future product positioning change of the Power Quality Analyzer and the fundamentals of *power factor* will be explained. In the next chapter the problem description will be presented.

A company profile of Benchmark Electronics is provided in Appendix A.

2.1 Fluke Corporation

Fluke Corporation is an American multinational company that designs, manufactures and markets electronic industrial test and measurement tools and software. Started by the late John Fluke, Sr. in 1948, it is a wholly owned subsidiary of Danaher Corporation since 1998. Danaher is a large diversified technology company headquartered in Washington, D.C.

Fluke's products include various types of digital multimeters, portable oscilloscopes, power quality analyzers, thermal imagers, calibration instruments, air quality meters, vibration testers and other specific test and measurement tools (Fig. 1). They mainly serve blue-collar professionals in the fields of production, maintenance, installation and engineering, who use them to measure, generate and make sense of electrical and other kinds of physical phenomena.

Fluke operates according to the following mission statement (Fluke Corporation, n.d.): "Fluke's mission is to be the leader in compact, professional electronic test tools."

The company maintains 21 offices worldwide, employing some 2,400 people. It runs manufacturing operations in the United States, the United Kingdom and China, while its headquarters are in Everett, Washington.

2.1.1 Fluke Products

While many of them may not be considered "handheld", Fluke's products are generally praised for their portability. Much effort goes into making the devices as compact as they can be, since most are intended for field applications that require them to be carried around with ease.

Fluke's tools help to make sure business and industry around the globe are running as they should. Their capabilities often have mission critical status and users stake their reputations on them. For this, and because they are commonly used in harsh and dangerous environments, the tools must be reliable and adhere to rigid standards of quality. Accordingly, their thick yellow-gray plastic exterior shells and internal components are designed and tested to withstand severe punishment and ensure accurate functioning at all times.

Sixty-three years after its foundation, Fluke has become a well-established leader in the test and measurement industry. Product innovation is considered to be an essential component to its success. The company strives to be at the forefront of technological development and is committed to trying to understand exactly what their customers' needs are. It has introduced such innovative products as a vibration tester that uses sophisticated diagnostic technology (Fig. 2), and a multimeter that conveniently comes with a detachable display (Fig. 3)—allowing the device to be operated from a distance. In the past five years, Fluke's tools have won more than 50 industry awards (Fluke Corporation, n.d.).

Figure 1: A collage of Fluke products

Figure 2: Fluke 810 Vibration Tester

Figure 3: Fluke 233 Remote Display Multimeter

2.1.2 The Almelo Facility

From 1993 until 1999, the Almelo division of Benchmark operated under the banner of Fluke and was named the Almelo Industrial Center (AIC). The AIC planned, designed and manufactured Fluke branded industrial test and measurement tools. It formed the basis of the company's Diagnostic Tools Division. As such, its focus was on the development of a successful line of portable oscilloscopes, called ScopeMeter (Fig. 4, Fig. 5).

Figure 4: A recent ScopeMeter product (Fluke 190-202)

Figure 5: Assorted Fluke ScopeMeters

Portable oscilloscopes are handheld test instruments that can graphically present the cyclical course of an electrical signal through time. They are used as multi-purpose diagnostic tools in the production and service of electrical and electronic equipment.

When the AIC was sold to Pemstar, its relationship with Fluke endured, as it became an EMS provider to its former owner. Fluke test and measurement tools continued to be developed in Almelo much like before. At present, the facility is still maintaining close and productive relations with Fluke.[1] Since 1999, it has been producing Power Quality Analyzers in addition to ScopeMeters (Fig. 6). At a glance, these devices appear very similar to ScopeMeters. In fact, however, they are fundamentally different devices in terms of functional capabilities.

Figure 6: Two of Fluke's Power Quality Analyzers

2.2 The Power Quality Analyzer

Fluke's Power Quality Analyzers are portable, professional tools that can measure a number of electrical parameters indicative of *power quality* in power distribution systems. They are used primarily to troubleshoot power problems and maintain power systems at industrial, office and public locations. Their users may include electrical technicians, engineers and scientists.

2.2.1 Power Quality Defined

Power quality is defined as the degree to which the delivery and utilization of electric power affect the performance of electrical systems (Ryan, 1996). The term is used to describe electric power in alternating current (AC) power distribution systems. Any deviation to the ideal sinusoidal voltage waveform shape can be regarded as a *power quality disturbance* (Ryan, 1996).

Power quality disturbances can originate at the side of the electricity consumer, in power distribution systems and electrical loads, or at the side of the electric utility, in electricity

[1] Adjacent to the premises of Benchmark, Fluke maintains a small office to manage distribution and supervise development of its products.

generators, power transmission systems and power distribution systems. Potential power quality culprits may include lightning, large equipment starting up or shutting down, improper electric wiring and grounding, and overloaded electric circuits. Often, the exact causes are quite elusive.

Disturbances are classified into different categories, such as *sags*, *swells*, *under-/overvoltage*, *harmonic distortion*, *noise*, and *transients* (Fig. 7). Depending on their magnitude and duration—and importantly, the affectability of the electrical systems involved—they have consequences of varying severity. In Europe, the EN 50160[2] norm provides limits and tolerances, beyond which the disturbances may be considered unacceptable.

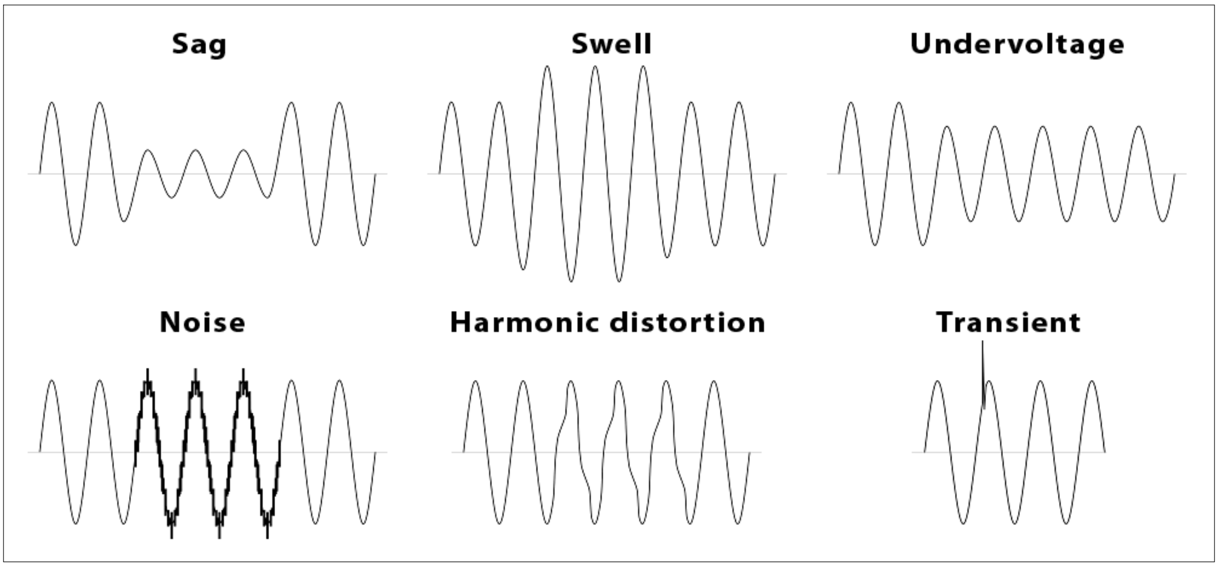


Figure 7: Typical waveform shapes of a sag, a swell, undervoltage, noise, harmonic distortion, and a transient

2.2.2 Power Quality Consulting

Businesses have strong incentives to manage the quality of their power. Electric power that is of insufficient quality can cause electrical equipment to malfunction, fail prematurely or not even work from the outset—microelectronics are especially vulnerable in this regard. It can also lead to reduced power efficiency, which may drive up energy costs. In 2007, poor power quality was estimated to be costing European business over €150 billion per year (Leonardo Energy, 2008).

When unable to solve their power quality troubles by themselves, businesses will enlist the help of *power quality consultants*. These specialist electrical engineers are typically employed by *power quality consultancies*, electrical contractors, and electric utilities. They will conduct on-site investigations into the power quality problems of their clients, using power quality analyzers. The investigations will generally result in recommendations of

[2] In full: European Norm 50160:2000, *Voltage characteristics of electricity supplied by public distribution systems*

power quality solutions, which often entail the installation of *power quality protection equipment* at the customer's premises.[3]

The power quality analyzer is an indispensable tool for any power quality consultant. It is greatly depended upon in locating, predicting, preventing and troubleshooting problems in power distribution systems. In operation, the device will typically be connected to the customer's facility's power distribution panel at the utility service entrance, by means of voltage leads and current clamps (Fig. 8, Fig. 9). It will record, monitor and analyze—often for an extensive period of time—various key power quality parameters according to the stringent IEC 61000-4-30[4] standard of measurement. Through its integrated LCD, the analyzer will provide measuring results and norm-referenced diagnostic information that will aid the power quality consultant in his analysis of the power quality issues he is confronted with.

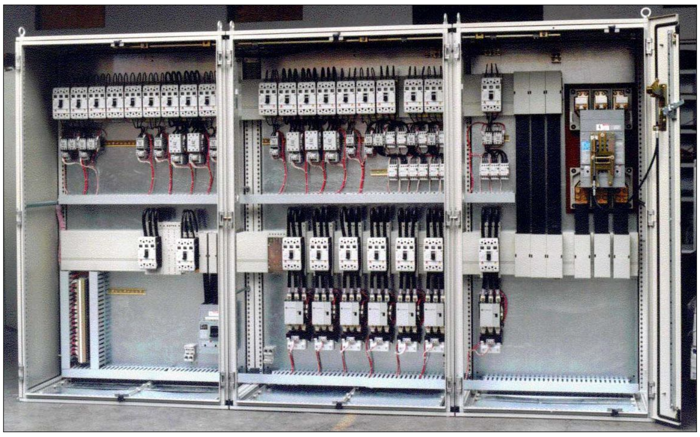


Figure 8: A typical power distribution panel

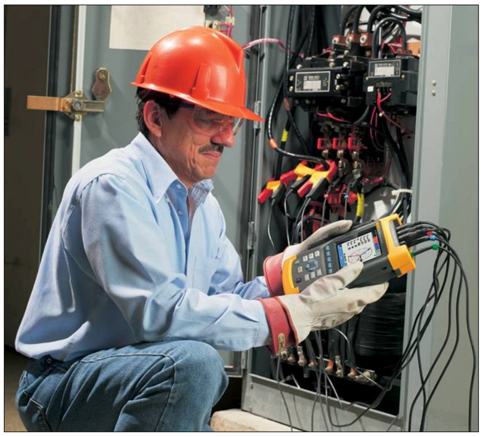


Figure 9: A power quality analyzer connected to the power distribution panel

2.2.3 Fluke Power Quality Products

Fluke's Power Quality Analyzers are part of the company's Power Quality Tools group of products. In addition to power quality analyzers, Fluke offers *power quality loggers*, *power quality recorders* and *power quality clamp meters*. Since the launch of its first power quality product in 1994, Fluke has steadily become a major participant in a large and growing market for power quality test and measuring equipment.

Fluke's current line of Power Quality Analyzers consists of two products:

- the 43B Single Phase Power Quality Analyzer (Fig. 10);
- and the 430 Series Three Phase Power Quality Analyzer (Fig. 11);

[3] Power quality protection equipment include *surge suppressors*, *voltage regulators*, *power conditioners* and *uninterruptable power supplies*.
[4] In full: International Electrotechnical Commission 61000-4-30, Testing and measurement techniques – Power quality measurement methods

Figure 10: Fluke 43B

Figure 11: Fluke 430 Series

Both have been developed at what is now Benchmark's Almelo location. The "43B", which has been in production since 2004,[5] has only basic power quality analysis capabilities. It is designed to take *single-phase*[6] measurements of electric systems and is used solely for troubleshooting and maintenance purposes. The "430 Series" offers more advanced functionality and improved measuring accuracy over the 43B. It comprises two models, the "434" and the "435", which were introduced in 2006 and 2008, respectively. There are only minor differences between the two. Both allow measurements to be taken simultaneously on all three phases of *three-phase*[7] electric systems and are intended to be used for an extended range of power quality analyzer purposes.

2.2.1 An Overview of Thor

The Fluke 430 Series Three Phase Power Quality Analyzer, being the most recent finished product, was chosen as a basis for the design of new Power Quality Analyzer functions and user interface parts. Within Benchmark and Fluke it is codenamed "Thor"—after the hammer-wielding Norse god of thunder and lightning. This name seems fitting for an electrical device that exudes ruggedness, no-nonsense and authority through its general shape, exterior elements and color scheme.

Thor is described as a high-end power quality troubleshooter. It has four input channels for simultaneous measurement of voltages and currents on all four conductors of a three phase power distribution system; it features gapless sampling at a rate of 200 kS/s on each channel; and it can measure voltages up to 6 kV. By virtue of its 0.1 percent voltage

[5] The 43B is but a slightly upgraded version of the "43", which was introduced already in 1998.

[6] The term "single-phase" refers to the distribution of alternating current electric power using a system in which the sinusoidal voltage waveforms on its circuit conductors are in phase with each other. The voltages on the circuit conductors thus vary in unison. A single-phase analyzer is designed to take measurements on one circuit conductor at a time.

[7] The term "three-phase" refers to a system in which the sinusoidal voltage waveforms on its three circuit conductors are 120° out of phase with each other. The voltages on the three conductors therefore reach their instantaneous peak values at different times. Three-phase electric power is the most common method used by electrical grids worldwide to transfer power. A three-phase analyzer is designed to take measurements on all three circuit conductors simultaneously.

accuracy, the 435 model is fully compliant with the very stringent “Class A” of the IEC 61000-4-30 standard of measurement.

Thor always automatically records all measuring results shown on its display, and offers the possibility to store them in its internal memory for future retrieval. The device can also be configured to automatically log over 400 power quality parameters at user defined intervals. When transferred to a pc with FlukeView analysis software installed, measurement data can be used to generate graphs and reports with.

The applications of Thor are listed as follows (Fluke Corporation, 2009):

- *frontline troubleshooting and predictive maintenance*—analyzing a power system to quickly locate, predict, prevent and troubleshoot power quality issues;
- *electrical load capacity verification*—analyzing a power system to determine if it has enough electrical capacity to handle proposed, additional electrical loads;
- *cost of energy assessment*—analyzing a power system to quantify the electricity cost reductions that can be achieved by taking certain measures;
- *incoming power quality validation*—monitoring voltages at the utility service entrance to determine whether the electric utility is the source of any power quality issues;
- and *long-term and intermittent analysis*—monitoring voltages and currents over long periods of time to uncover hard-to-find or intermittent power quality issues.

Figure 12: Thor exterior design

Thor measures about 256 mm x 169 mm x 64 mm (h x b x d) in size (Fig. XX). At the front it features a 115.2 mm x 86.4 mm color LCD and several sturdy input keys; at the top it has a series of large inputs connectors for current clamps and for voltage leads; and at the back it has a tilt stand that allows viewing the screen at an angle when placed on a flat surface. Weighing in at 2 kg, Thor may not be the wieldiest of portable test tools. It can, however, operate for more than seven hours on a single charge of its battery.

Thor meets the stringent *600 V CAT IV*, and *1000 V CAT III*, safety standards required for measurement at the utility service entrance.

2.3 The significance of Power Factor

At Benchmark Almelo, a successor to Thor is currently being developed. This new product is in an early prototype stage and is due for launch in 2012. Officially dubbed the "430 Series II Three Phase *Energy Analyzer*", it breaks with the present product naming tradition. The name change reflects a shift in emphasis within the product towards functionality for cost of energy assessment. Fluke will try to position its future three-phase analyzers more prominently as tools that help businesses make informed decisions on how to bring down the cost of their energy consumption. Considering ever-rising energy prices and increasing public awareness of energy efficiency, the company foresees a greater market demand for such products.

Poor energy efficiency in a power distribution system is not necessarily attributable to a power quality issue. Equipment such as motors, transformers, busbars and cables can be "at fault" in different ways. Very often the single major cause of inefficiency is excess power that is flowing through a power system when this system has what is known as a low *displacement power factor*. Although it is associated with power quality, displacement power factor is not normally considered a power quality parameter.

The instigation of the product positioning change means displacement power factor is currently receiving increased attention from Benchmark and Fluke.

2.3.1 Power Factor Explained

Displacement power factor—henceforth simply named *power factor*—is an indicator of the efficiency of an AC power distribution system. It is defined as the ratio of the *active power*, which is used by the electrical loads to perform work, to the *apparent power*, which is flowing through a power distribution circuit (reference); it is a dimensionless number between 0 and 1, or *nil* and *unity*. A power factor near unity is most desirable.

Strictly speaking, power factor is not a power quality parameter as it describes a relation between voltage and current, whereas power quality typically only relates to voltage.

Power factor is given by the formula:

$$Power\ Factor = \frac{P}{|S|}.$$

Apparent power ($|S|$, often just S), measured in *volt-amperes* (VA), is the total power required by a power system. It is the product of the root-mean-square of the voltage and the current of a power circuit. Active power (P), measured in Watts (W), is that portion of the apparent power that results in a net transfer of energy to the loads over a complete cycle of the AC voltage. It is converted by the electrical loads into electromagnetic, mechanical, and other forms of power.

Power factor is a way of measuring the relative amount of *reactive power* in a power system. Reactive power (Q), measured in *reactive volt-amperes* (var), is that portion of the apparent power that results in no net transfer of energy to the loads over an AC cycle. It is power that is not used by the electrical loads to perform work, but instead is returned to the source. In a sense, it is wasted power—although many loads cannot do without it. The amount of reactive power in a power system is determined by the nature of the electrical loads.

In an electric system with a purely *resistive* load, such as an electric heater, the voltage and current waveforms intersect the time axis at the same point (Fig. 14). As they are “in phase” with each other, the power waveform resulting from their product has only positive instantaneous values (Fig. XX). This indicates that, in each AC cycle, all of the power in the circuit is flowing in one direction, and is used to perform work in the load. Thus, in case of a purely resistive load, the active power equals the apparent power—resulting in a power factor of unity—and no reactive power is transferred.

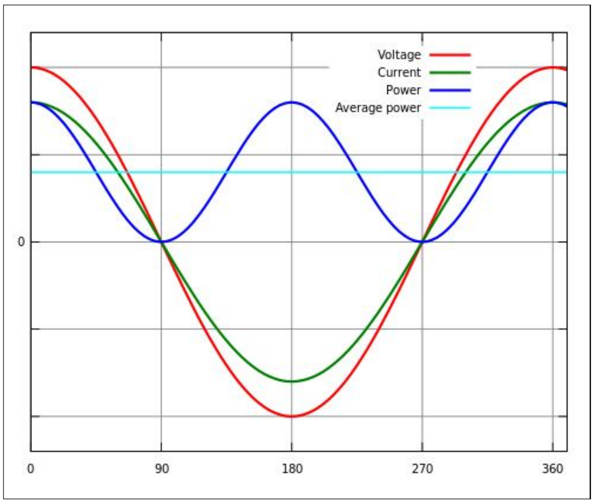


Figure 13: Voltage, current and power waveforms with a purely resistive load

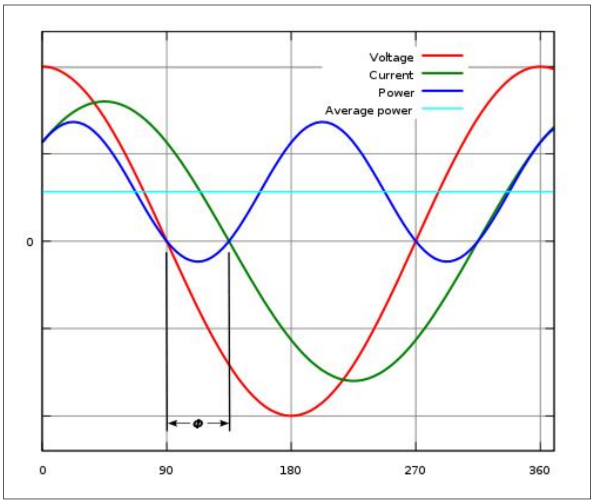


Figure 14: Voltage, current and power waveforms with a partially reactive load

With a partially *reactive* load, such as an electric motor, the voltage and current waveforms do not intersect the time axis at the same point (Fig. 15). A partially reactive load has a resistive and a reactive component. The reactive component consists of capacitive and or inductive elements, which, during part of the AC cycle, store some of the energy from the power circuit in their electric or magnetic fields, only to return this energy during the rest of the cycle. This causes a current to flow back and forth between the load and the power generator, asynchronous to the AC voltage—either “lagging” it or “leading” it by exactly 90°.

The adding together of *resistance*- and *reactance*-induced currents, creates a *phase shift* (φ) between the voltage and current waveforms. As they are “out of phase” with each other, the power waveform has negative instantaneous values. This indicates that, in each AC cycle, some of the power in the circuit is not used by the load to perform work, but instead is returned to the source. Thus, in case of a partially reactive load, the active power is less than the apparent power—resulting in a power factor of between nil and unity—and reactive power is continuously flowing back and forth between the load and the generator.

The higher the reactance of the load; the larger the phase shift between the voltage and current waveforms; the lower the power factor; and the higher the reactive power. In an electric system with a purely reactive load, such as a capacitor or an inductor, the load will cause a maximal phase shift of 90°. Only reactive power will flow through the system, as it will return all the power it will receive. The power factor will then be nil.

The exact relation between active power, reactive power, apparent power, and phase shift (φ) is conveniently described by the *power triangle* (Fig. 16)—provided the waveforms are perfectly sinusoidal. The power triangle is an often used concept in power engineering. In it, *phasors* are used to express active power (P), reactive power (Q) and *complex power* (S), such that:

$$S^2 = P^2 + Q^2.$$

Phasors are simplified representations of sine waves, using vectors in the complex plane. Complex power (S), measured in *volt-amperes* (VA), is the vector sum of active power (P) and reactive power (Q). Apparent power ($|S|$) is simply the modulus, or absolute value, of complex power (S).

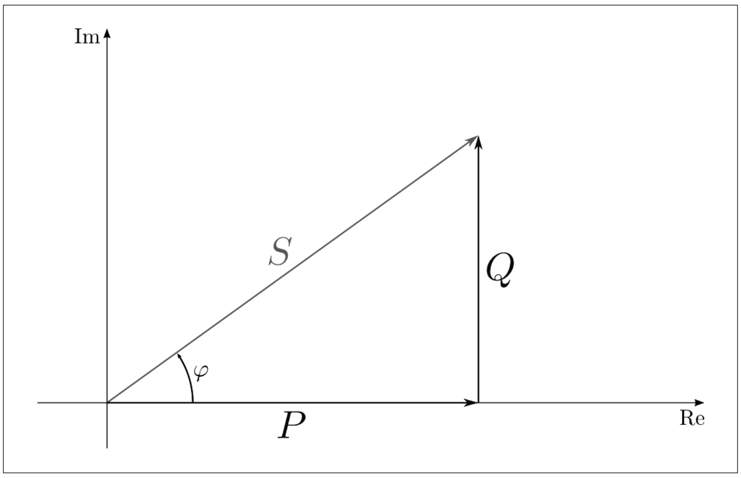


Figure 15: The power triangle

From the power triangle it can be derived that the power factor is equal to the modulus of the cosine of phase shift (φ), as presented by the formula:

$$Power\ factor = |\cos\varphi|.$$

This is why power factor is often abbreviated as "cos φ" or "cos phi".

2.3.2 The Costs of a Low Power Factor

An electric system with a low power factor will have several disadvantages over one with a high power factor. At the heart of these disadvantages lies the fact that for two systems transmitting the same amount of active power, the system with the lower power factor will have higher circulating currents—due to higher reactance-induced currents—than the system with the higher power factor. Increased currents in a system pose a number of problems.

Firstly, higher currents bring about energy waste. This is due to higher *copper loss*, or I^2R *loss*—heat converted from electrical energy in the conductors of a power system. A low power factor thus signifies an inefficient use of energy. It is associated with substantial energy transmission and distribution losses. Businesses affected by a low power factor bear most of the cost of these losses through higher electricity bills: their energy use is higher, as are the tariffs set by the electric utility.

Rising energy prices worldwide cause the economic impact of a low power factor to be felt ever more strongly. Also, growing concerns about CO_2 emissions make it a topic that is increasingly seen in an ethical light as well.

Secondly, higher currents cause a greater *voltage drop*—the reduction in voltage that occurs in the conductors of a power system. This is also due to higher copper loss. Excessive voltage drop can result in undervoltage, a type of power quality disturbance. A low power factor thus influences power quality. It may lead to unsatisfactory operation of electrical equipment and may even cause damage to it.

Lastly, higher currents push generators, switchgear, transformers and conductors closer to their rated current carrying capacities. A low power factor thus represents an inefficient use of power transmission and distribution equipment. It decreases a power system's ability to withstand current surges. If rated current carrying capacities are exceeded, equipment may overheat and cause an electric system to fail.

Also, it reduces a power system's capacity for load expansion. In order to expand their loads, businesses with power systems that have capacity problems and low power factors may decide to upgrade their systems—at great financial cost—when often they could make do with the same systems had these had higher power factors.

Electric utilities face a similar problem. A low power factor reduces power generation, transmission and distribution systems' capacity to serve new customers. All the while, businesses are usually not charged by the utility for the current capacity they use as a result of the reactive power they generate.

To recoup the financial cost of excessive loss of current capacity caused by low power factor businesses, electric utilities impose a *reactive demand charge* on such customers. Utilities expect this compensation when reactive power exceeds a certain level, often 50% of active power—corresponding to a power factor of 0.85. For low power factor businesses, most of the financial cost of a low power factor is in the reactive demand charge.

2.3.3 How to Correct a Low Power Factor

Many businesses struggle with power distribution systems that have low power factors. They would be much better off if their power systems had power factors near unity. Fortunately for them, there exist relatively inexpensive and "non-invasive" methods to increase the power factor of a power system. These methods do not involve major overhauling of an electric system, but only rely on the placement of special *power factor correction equipment* at selected points in a power circuit.

The crucial components of this equipment are *capacitor banks* (Fig. 16). These are groups of large, specially constructed capacitors that serve to compensate for the reactance of partially *inductive* loads—loads with reactive components that mostly consist of inductive elements.

Figure 16: A series of capacitor banks at a large industrial facility

Partially inductive loads are by far the most common type of partially reactive load. Among them are the most important contributors to a low power factor: variable-speed electric motors. Such motors are used in compressors, conveyors, fluorescent lighting and many types of manufacturing equipment. Because of this, power factor problems are primarily set in industrial facilities, such as sawmills, foundries, chemical plants, polymer plants, textile factories and automotive factories.

Inductive loads differ from *capacitive loads* in the phase shift between the reactance-induced current they create and the AC voltage. Inductive elements in inductive loads produce currents that lag the AC voltage by exactly 90°, whereas capacitive elements in capacitive loads produce currents that lead the AC voltage by exactly 90°.

The reactance-induced current waveforms created by both types of load are complete opposites, as they are shifted 180° in phase from each other. Hence, at the same time that inductive loads store reactance-induced current, capacitive loads return it, and vice versa.

This notion is made use of in power factor correction. Naturally, capacitor banks act as capacitive loads. If they are connected to partially inductive loads, capacitors and loads can take turns in supplying each other with reactance-induced current, thus endlessly cycling this current between them. This way, they can be said to cancel out each other's reactance.

In a setup where capacitors and loads are close together, reactance-induced current will not travel long distances through the conductors of power distribution and transmission systems (Fig. 17). The amount of current flowing through the conductors between the loads and the generators of the electric utility will be reduced. Less reactance-induced current will be needed from the electric utility, and the power factor of large parts of the power distribution and transmission systems will be increased.

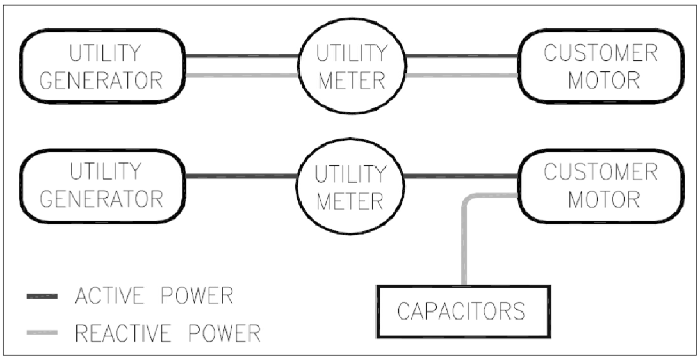


Figure 17: A capacitor connected to a load; reactive power is diverted

2.3.4 Power Factor Consulting

To increase the power factor of their systems, businesses will typically hire broad-oriented power quality consultants, or more specialized electrical engineers who could be called *energy consultants*. Power factor consulting has a lot in common with power quality consulting—which it is often considered a subset of. It is a sophisticated process involving computer analyses and on-site examinations in which power quality tools are often used.

During a power factor investigation power quality analyzers are used in much the same way as in a power quality investigation. However, a smaller set of analyzer functions is used. Thor currently offers limited functionality to investigate power factor. In Donar, this functionality will be expanded.

The investigations will generally result in recommendations of power factor solutions, which involve the installation of power factor correction equipment at the customer's premises.

2.3.5 An Overview of Donar

Within Benchmark and Fluke the future 430 Series II Three Phase Energy Analyzer is codenamed "Donar"—the southern Germanic variant name of Thor. The most important change in Donar with respect to Thor is the presence of "troubleshoot functions" for power and energy analysis (Van Alphen, 2011): Donar will be able to better assist the user during power and energy analysis. It will feature clever algorithms, by which it is able to calculate the effects on energy efficiency of five electrical parameters that are frequent causes energy inefficiency: conductor thickness, displacement power factor, *harmonic distortion*, *phase unbalance* and *neutral current* (Van Alphen, 2011). Significantly, the product will also be able to make power and energy analysis results more tangible by expressing them in monetary terms.

With Donar, Fluke seeks to capitalize more fully on energy efficiency market trends. The company recognizes that energy efficiency is a topic of ever-increasing importance in business circles. Globally, energy prices are rising as non-renewable energy sources are becoming scarce, and fear of global warming is leading to more stringent standards on CO_2 emissions. It also finds that businesses generally have more feeling with concepts of energy efficiency than concepts of power quality, since energy efficiency is more readily expressed in monetary terms than power quality.

3 Problem Description

Benchmark Almelo and Fluke are developing Donar, the successor to Thor—Fluke's three-phase power quality analyzer. Donar is to have improved functionality that will make power and energy analysis a little more convenient. It will assist the user in calculating the effects of certain electrical parameters on energy efficiency, and expressing energy inefficiency in monetary terms.

Benchmark believes that power and energy analysis will remain a focal point for the Analyzer. The company holds a vision of future product developments beyond Donar. There are two aspects to this vision. Firstly, Benchmark thinks much more could be done in the way of adding assistance functionality to the instrument. The deployment of comprehensive "job assistance" features could make power and energy analysis a less demanding, more efficient, and more satisfying job to perform. Existing Analyzer users could thereby see improvements in productivity. Perhaps more importantly, new users could be drawn to the Analyzer: lesser trained, "blue-collar" electrical technicians could perform power and energy analyses alongside ordinary energy consultants. Benchmark supposes this would spell an opportunity for Fluke to expand its customer base and sell more Analyzers.

Secondly, it thinks the appeal of the Analyzer could be boosted by adding touch screen functionality. Currently, the market is beginning to see the introduction of touch screen technology in three-phase power quality analyzers. Fluke is not at the front of this development; none of Fluke's power quality products is presently featuring touch screen technology. However, Benchmark believes it will definitely be coming to Fluke's Power Quality Analyzers in the not too distant future. The benefits of using touch screen technology in the analyzers include a larger screen size, higher durability, and a generally more usable interface. Furthermore, it could help facilitate the deployment of job assistance features.

Benchmark thinks a future design concept study should have to be executed, to shape its ideas further and present them to Fluke. For optimal illustration of the ideas, the focus of the study should lie on the creation of a "showcase design" of a new *user interface* for the Analyzer. The company is interested in how new job assistance features and the touch screen technology could come together in the user interface to make the Analyzer a more accessible, more usable, and more appealing instrument to carry out power and energy analyses with. The new user interface should be designed to become viable five years from now.

When contemplating the efficiency of power distribution systems, power factor should come to mind. Many businesses deal with power distribution systems that have low power factors, and are incurring significant financial losses as a result. Power factor analysis is an important aspect in reducing the cost of energy of these businesses. It is a process that draws heavily on the experience and expertise of energy consultants, due to the intricacies of the problems involved. Therefore, Benchmark regards it as the perfect vehicle to showcase the design of new job assistance features and touch screen functionality with.

4 Design Analysis

This chapter covers the analysis phase.

4.1 An Overview of Power Factor Solutions

In order to develop a user interface that supports job assistance features, it is helpful to know a bit about the solutions that are devised in power factor analysis.

4.1.1 Power factor Correction Methods

There are four principal methods of correcting power factor through the placement capacitor banks in a power circuit. They are listed as (Lefrank, 2002):

- Individual power factor correction
- Group power factor correction
- Central power factor correction
- Hybrid power factor correction

The following will briefly highlight each method, its applications, its advantages and its disadvantages:

- **Individual power factor correction**

  Simplest method of power factor correction. An appropriately sized capacitor bank is placed in parallel with each inductive load. This eliminates all reactive current flowing through the conductors. Can be used to increase system's capacity for load expansion.

  Advantage: simple installation.
  Disadvantage: high installation costs.

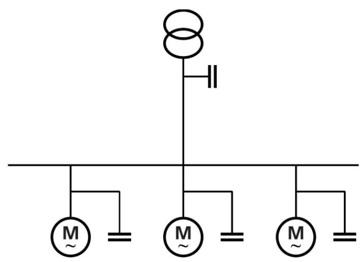


Figure 18: Typical individual power factor correction

- **Group power factor correction**

  Electrical machines that are always switched on at the same time can be combined as a group and have a joint capacitor bank.

  Advantage: more cost effective than individual correction.
  Disadvantage: only for groups of loads that are always operated at the same time.

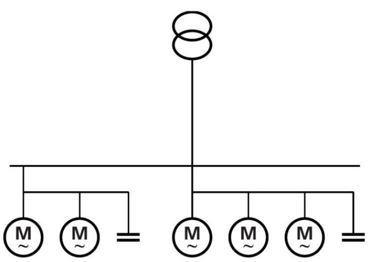


Figure 19: Typical group power factor correction

- **Central power factor correction**

  The correction equipment is installed at the power distribution panel. Most frequently used. Primarily aimed at eliminating the reactive demand charge imposed by the electric utility.

  Advantages: can always be used where power system has sufficient capacity; easy to monitor; relatively simple installation. Disadvantage: reactive current in user's power distribution system is not reduced.

- **Hybrid power factor correction**

  For economic reasons the three methods described above are often combined.

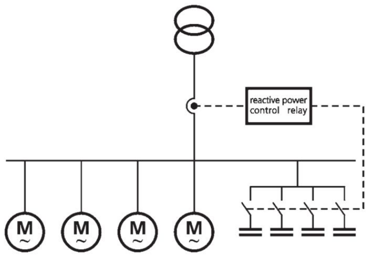


Figure 20: Typical central power factor correction

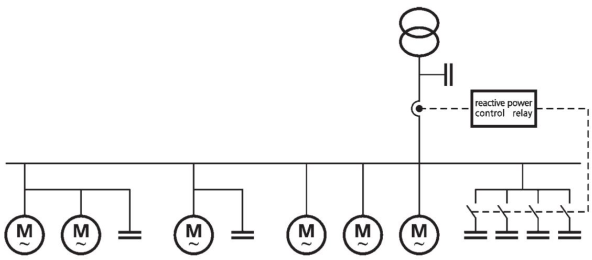


Figure 21: Typical hybrid power factor correction

4.1.2 Power Factor Correction in the Presence of Harmonics

Oftentimes, power factor analysis is complicated by *harmonics*, which are periodic distortions of voltage, current, or power waveforms (Fig. 22). Harmonics are produced by modern electronic equipment, such as computers and printers.

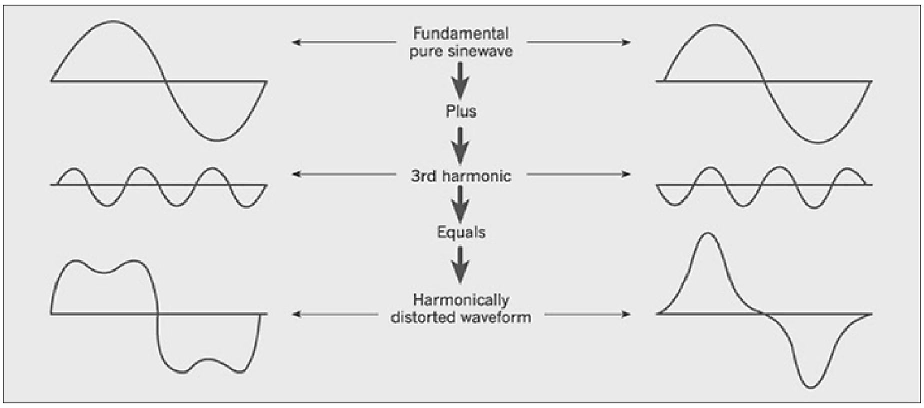


Figure 22: Harmonic distortion

Capacitor banks can amplify harmonics to unacceptable values. An effective measure to reduce harmonics and their detrimental effects on the power distribution system is to install *active harmonic filters*.

4.2 Methods of providing job assistance

4.2.1 Setup Assistant

A *setup assistant* or *software wizard* (Fig. 23) is a type of user interface that presents a user with a sequence of dialog boxes that guide the user through a series of well-defined steps. Tasks that are difficult, infrequently carried out, or unfamiliar may be easier to complete with the use of an assistant.

Figure 23: Typical software wizard example

A dialog box typically contains a "next" option that is selected to move to the next dialog box after entering or configuring information in the present dialog box. A dialog box usually also provides a "back" option that is selected to go to the previous dialog box. The last dialog box in a setup assistant sequence typically presents a "finish" option that is selected to close the setup assistant.

4.2.2 Interface Agent

One way of providing job assistance to users is implementing *software agents*. A software agent is a piece of software that acts on behalf of the user in a rational and autonomous way.

4.2.3 Power Factor Expert System

An excellent way of providing job assistance to users is to implement an *expert system* in the power quality analyzer. In artificial intelligence, an expert system is a computer system that emulates the decision-making ability of a human expert (Jackson, 1998). Expert systems are designed to solve complex problems by reasoning about knowledge, like an expert, and not by following a fixed procedure programmed by a software developer.

An expert system for power factor analysis has been shown to work (De Oliveira, Martins, & Gonçalves, 2000). A software application can be devised that optimally distributes capacitor banks and harmonic filters within a power distribution system. There is nothing that would hinder its use in a power quality analyzer.

If an expert system can be trusted to make all decisions and perform all calculations involved in power factor analysis in correct fashion, the power quality analyzer's job assistance functionality can be expanded in the following manner:

- The analyzer can decide when, where, and for how long measurements of a power system need to be taken.
- The analyzer can interpret the measuring results and recommend a proper solution to a power factor problem.
  - The analyzer can propose an optimal distribution of capacitor banks in a power system.
  - The analyzer can propose the placement of harmonic filters in a power system, when necessary.
- The analyzer can outline the financial savings that are made by implementing a solution.

4.3 An Interview with a Consultant

An interview was conducted with the owner of a small power and energy consultancy in Hengelo, The Netherlands. The purpose of the interview was to find out in some detail how energy consultants carry out their jobs, to learn about the difficulties they experience while executing their work tasks, and to discover their wishes for job assistance features.

The interviewee was an energy consultant who had many years of professional experience in the field of power factor consulting, serving industrial businesses throughout The Netherlands. He offered power factor consulting, equipment ordering and equipment maintenance services, mostly to industrial customers.

The next subsections summarize the findings of the interview.

4.3.1 The Consultants Work Process

The following is a description of the consultants work process:

1. When a customer calls, the consultant will set up an appointment for a visit. At the customer's facility, he will first study the customer's monthly energy bills and network schematics to get an overview of the situation. He will then perform measurements, using his power quality tools, usually at selected points on the facility's main (and sub) distribution panel.
2. The entire measurement process will either take a few hours or a week to complete, depending on whether the consultant is interested in present, momentary values or recordings of values over a longer time period. By recording parameters during a facility's entire cycle of operation (using his power quality analyzer) he can accurately identify peak values.
3. Next, when all necessary data is collected, the consultant will use specialized computer software at his office to perform an analysis. He will determine the appropriate power factor correction method, calculate the required *capacitor power rating* (and harmonic filter ratings), properly dimension the entire power factor correction system, and select suitable correction equipment.

4. Finally, the consultant will present his costumer with a detailed report of his analysis and will make him an offer (for the equipment necessary) to implement the proposed solution. He uses previous reports as templates for new reports.

- The consultant distinguishes between two types of customers: companies that wish to halt the incurrence of reactive demand charges by the electric utility, and companies that seek to enlarge their facility's electric network capacity to accommodate an expansion of production.
- The two types of customers the consultant discerns each require a different approach with regard to data collection.
    - In dealing with the first customer category, the consultant's power factor analyses are based primarily on a costumer's monthly energy bills and network schematics. The required capacitor power rating can, in most cases, easily be determined using the maximum active power (kW), active energy (kWh) and reactive energy (kVArh) figures listed in the electric utility's monthly invoice. Direct system measurements are used as a check, mainly to find out whether there is excessive harmonic distortion in the system—which can wreak havoc once the capacitors are installed.
    - In dealing with the second category, extensive measurements of the network form the basis of the power factor analyses. The consultant will take readings of the apparent power (kVA), real power (kW), reactive power (kVAr) and harmonic distortion (THD-I, THD-U and harmonic spectrum) at various branches of the network, so he can get a detailed picture of the network's capacity for load expansion.
- The consultant is not much concerned with the practical aspects of installing power factor correction equipment, as these are generally looked after by a customer's regular electrical contractor.
- When performing measurements, the consultant wears thick rubber gloves that are designed to protect against voltages up to 1000 Volts (Fig. 24). He prefers having them on for continuous stretches of time, because removing them and putting them on can be quite a hassle.
- The consultant has stated that equipment maintenance services form a significant part of his business. He will inspect air filters and capacitor contactors and replace them if necessary.

Figure 24: Rubber electrical gloves, 1000 V rated

4.3.2 The Difficulties Experienced

When asked about the difficulties he experiences in his job, the consultant made the following points:

- The consultant explained he often experiences difficulty in measuring voltages at the main distribution board, due to the measurement locations being in cramped and poorly accessible spaces. He said this is typical of European-style distribution units. American-style units generally are much more spacious.
- Measuring currents can pose difficulty as well when there is little space around the power cables for attaching current clamps. Instead of applying clamps, the consultant may use flexible current probes (colloquially called “dog collars”) in such cases.
- Drawing upon his extensive know-how, the consultant generally has little trouble performing his analyses. When pressed to name to most challenging parts of the analysis process, he pointed to the calculations involved in dimensioning a power factor correction system with regard to harmonic disturbance issues.
- Harmonics have a detrimental effect on the performance of an electric system. Power factor correction capacitors can grossly exacerbate harmonic disturbance issues and are adversely affected by them.
- The consultant noted care must be taken never to grossly “overdimension” the capacitor power rating.

4.3.3 Thoughts and Wishes related to job assistance

The consultant expressed the following thoughts and wishes with respect to job assistance in the power quality analyzer:

- The consultant thinks it is conceivable to create simple, but sufficiently accurate representations of customers’ power systems using an Analyzer type of device.
- The consultant reacted positively to the suggestion of integrating into the Analyzer the computer software he uses for his analyses. If he can perform at least part of his analysis on-site, he can communicate his preliminary findings at a much earlier time. This would be valued highly by his customers.
- The consultant would like the Analyzer to be able to calculate the capacitor power rating based on the power factor and vice versa.
- He supposed the Analyzer could help him prepare excel sheets and reports for sharing and printing (at the customer’s location).
- The consultant believes wireless internet technologies may offer interesting opportunities. The Analyzer may search external databases to provide instant, up-to-date information on products, services and prices.
- The consultant thinks a database in the Analyzer, containing all previously collected information on his customers’ power systems, will prove very convenient during maintenance work on his costumers’ power factor correction equipment.

These thoughts and wishes will feature as requirements in the requirements specification of chapter 6.

4.4 Thor User Interface

The Thor user interface consists of a keypad, an LCD, a device casing, a power connector, and input connectors for voltage leads and current clamps. This section will provide a brief description of the Thor user interface focusing on the keypad and the LCD.

4.4.1 Main Menu Layout

Thor offers an extensive and powerful set of measuring modes to check power distribution systems.[8] Some give a general impression of power system performance; others are used to investigate specific details. In the user interface, they are grouped into three main menu options: “SCOPE”, “MONITOR” and “MENU”. Each of these options has a dedicated key on the keypad (Fig. 25, item A).

SCOPE is used to get a clear view of the voltage and current waveform shapes and their phase relation, by means of *Waveform screens* (Fig. 26) and *Phasor screens* (Fig. 27). These may offer the first hints of any power quality problems present. Also, they provide a way to verify that the voltage leads and current clamps are connected correctly.

MONITOR is used to get a general impression of the power quality. It offers *Bar Graph screens* (Fig. 28), which show whether important power quality parameters exceed a certain set of limits. One such set is specified according to the EN 50160 norm. This option is generally used for long-term observation of a power system.

MENU is used to get in-depth information on various power quality parameters that are believed to cause trouble. It mainly provides *Meter screens* (Fig. 29), which give instantaneous overviews of many important numerical measuring values, and *Trend screens* (Fig. 30), which show the course through time of these measuring values. The Analyzer automatically records all readings in the Meter screens.

The main menu layout of Donar will differ slightly from Thor. It will switch the MONITOR main menu option with “LOGGER”, a measuring mode that is located under MENU.

Other menu options that have dedicated keys on the keypad are “SETUP”, “MEMORY” and “SAVE SCREEN” (Fig. 14, item B).

[8] The measuring modes are *Scope Waveform & Phasor*, *Volts/Amps/Hertz*, *Dips & Swells*, *Harmonics*, *Power & Energy*, *Flicker*, *Unbalance*, *Transients*, *Inrush Currents*, *Mains Signaling (optional in ‘434’)*, *Logger (optional in ‘434’)*, and *Power Quality Monitoring*.

Figure 25: Thor keypad and LCD

4.4.2 Controls and Screen Information

Operation of measuring functions and adjustment of settings is performed via screen menus. Four arrow keys are used to navigate through these menus (Fig. 25, item C). The "ENTER" key is used to make selections (Fig. 25, item E). The keys "F1" through "F5" (Fig. 25, item D) are soft keys that are also used to make selections. Each soft key corresponds with a soft key text area that may be selected. Soft key functions that can be selected are indicated by white-colored text; soft key functions that are currently not available are indicated by gray-colored text; and soft key functions that are presently selected are highlighted with a black background.

The following screen information is common for all screen types:

- Measuring mode (shown in the screen header, not visible in Fig. 25)
- Measuring values (Fig. 25, item G)—main numerical measuring values with background colors that differ per phase and for voltage or current.
- Status indicators (Fig. 25, item H)—symbols that may appear on the screen to show the state of analyzer and measurements.
  - *Items: indication that the 150/180 cycle aggregation interval is active; indication of time that a measurement has been going on; indication that horizontal zoom is on; indication that measurement may be unstable; indication that a dip, swell or interruption has occurred; indication that recording of measurement data is on; indication of phasor rotation or phase sequence; indication of battery or line power; and indication of keyboard locked.*
- Main area with measuring data (Fig. 25, item I)
- Status line (Fig. 25, item J)
  - *Items: date of the analyzer's real time clock; time of day or cursor time; nominal line voltage and frequency; GPS signal strength indicator; number of phases and wiring configuration for the measurement; and name of the limits used for the MONITOR option.*
- Softkey text area (Fig. 25, item K)

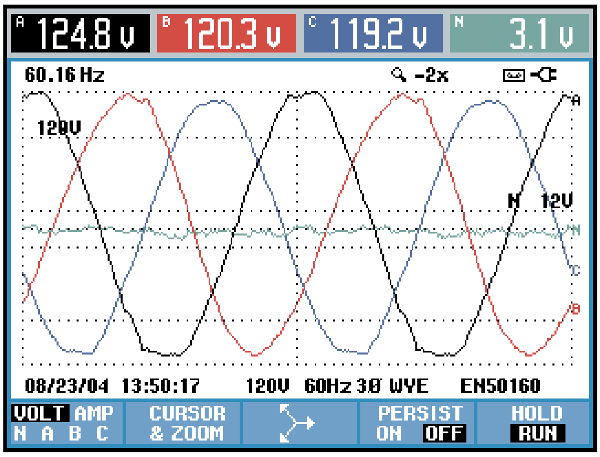


Figure 26: A Waveform screen

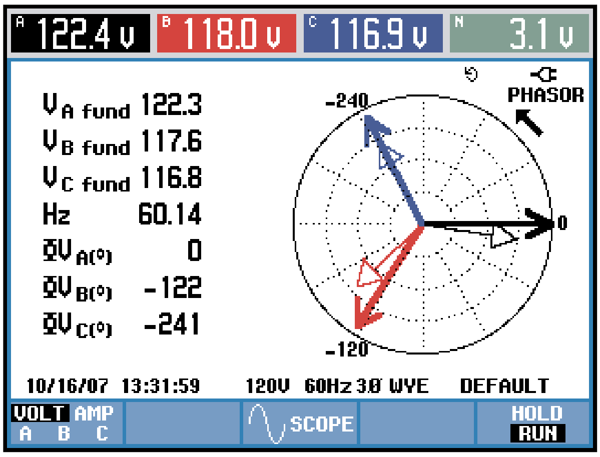


Figure 27: A Phasor screen

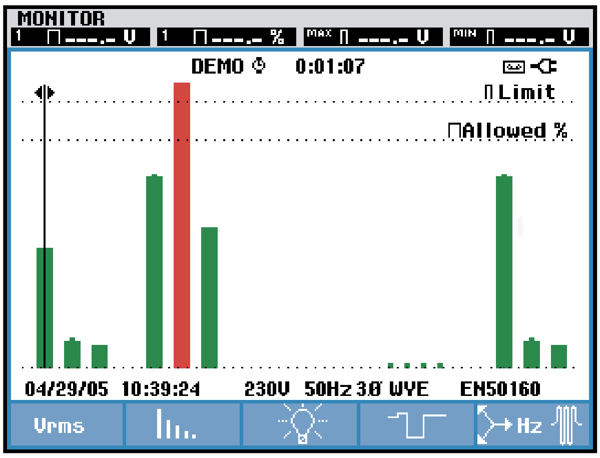


Figure 28: A Bar Graph screen

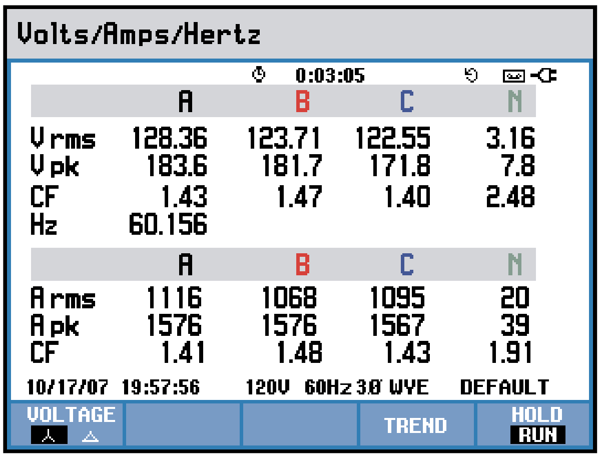


Figure 29: A Meter screen

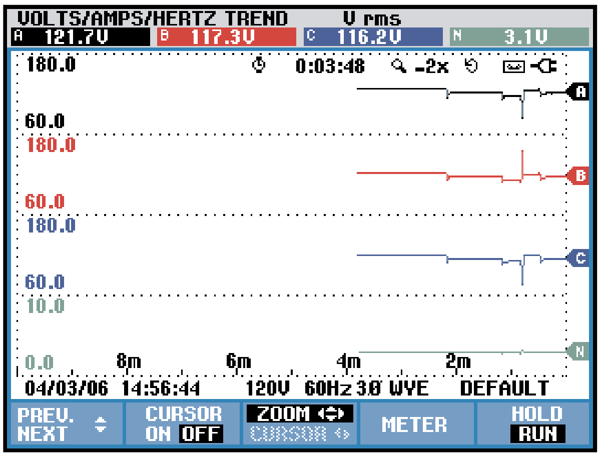


Figure 30: A Trend screen

4.4.3 Functions for Power Factor Analysis

Thor offers three measuring modes that are used in power factor analysis: "Power & Energy", "Harmonics" and "Logger". All three are located under "MENU".

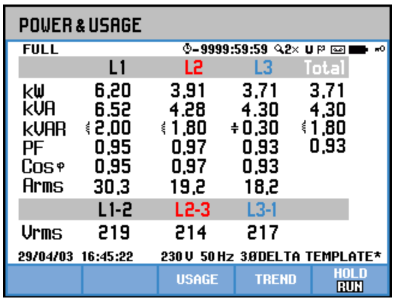


Figure 31: A Power & Energy Trend screen

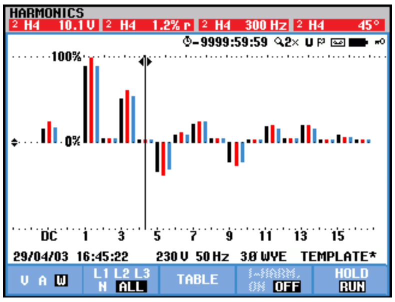


Figure 32: A Harmonics Trend screen

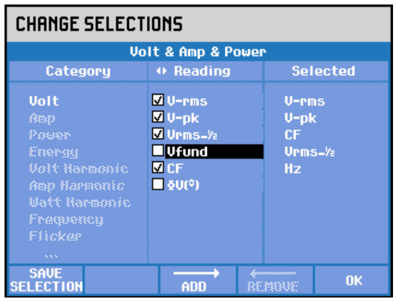


Figure 33: A Logger Trend screen

Power & Energy displays Meter screens and Trend screens. The Meter screens mainly provide measuring values of parameters that are related to power factor (Fig. 31). The Trend screens show the course through time of all measuring values in the Meter screens.

Harmonics displays a Bar Graph screens and a Trend screen. The Bar Graph screens show the distortion size of each of the harmonic components as a percentage of the full signal (Fig. 32).

Logger offers the possibility to store with high resolution the measuring values of multiple parameters over adjustable time intervals (Fig. 33).

4.5 The Market and the Competition

4.5.1 A Market Overview

The power quality test and measurement (T&M) equipment market is large and growing. It accrued revenues worth $556.7 million in 2009, and is estimated to accrue $697.6 million in 2016 (Frost & Sullivan, 2010). The market has many participants.

The power quality T&M equipment market consists of the following segments: *handheld devices*; *portable instruments*; *permanently installed monitors*; *power quality software*; and *revenue-demand meters with power quality features* (Frost & Sullivan, 2010). With its Power Quality Tools group of products Fluke mainly focuses on the handheld devices and portable instruments segments. Three-phase power quality analyzers such as Thor can be regarded as a subcategory of the portable instruments segment.

With regard to Thor, Fluke faces competition from three major participants—Chauvin Arnoux, Dranetz and Hioki Corporation—as well as several smaller participants. Competition in the three-phase power quality analyzer subcategory is based primarily on price, performance and features. A trend can be seen towards enhanced capabilities of the three-phase analyzers.

Fluke seeks to differentiate its high-end power quality analyzers from its competitors' through high specifications, high reliability, smart functionality, thoughtful user interface design, and distinctively rugged exterior design. It chooses to create high quality, "Class A" equipment, on which it can maintain healthy profit margins.

4.5.2 An Overview of Competitors' Offerings

The PowerXplorer PX5 440 (Fig. 34) is a power quality analyzer manufactured by Dranetz, one of Fluke's main competitors. The PX5 440 is the flagship model of the company's line of power quality analyzers.

Figure 34: Dranetz PowerXplorer PX5 440

The PX5 440 has the following characteristics:

- Size: 300 mm x 64 mm x 203 mm (h x w x d)
- Weight: 1.9 kg
- Display: 3.75 x 4.75 inches color touch screen LCD
- Input:
  - The touch screen is operable using finger or stylus.
  - The touch screen display permits alphanumeric data entry.
- Assistance features:
  - The instrument creates reports that show graphs and statistical tables reflecting the compliance to the EN50160 standard.

- There are three ways to set up the instrument for measuring:
  - Automatic Setup automatically configures the instrument's circuit type, voltage and current channels, and parameter thresholds.
  - Wizard Setup takes the user through a series of screens prompting for information about the circuit to be monitored.
  - Advanced setup allows the user to modify trigger parameters and intervals that were previously set up through Automatic or Wizard setups.

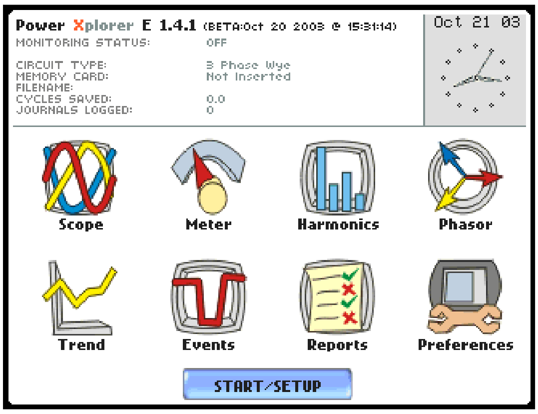


Figure 35: PX5 440 – Main menu

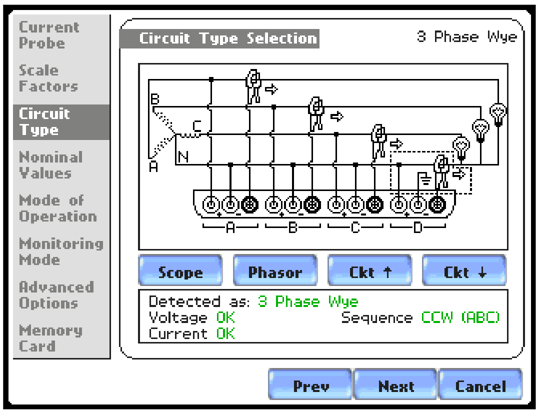


Figure 36: PX5 440 – Wizard screen 1

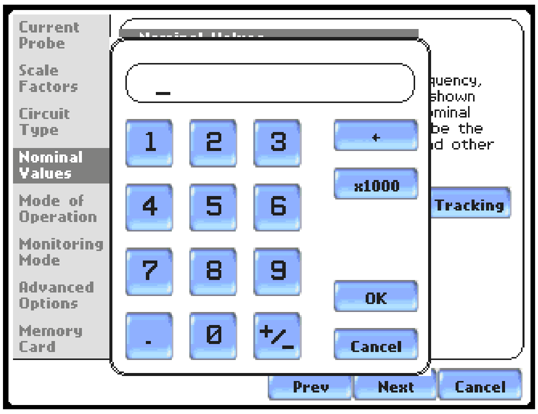


Figure 37: PX5 440 – Wizard screen 2

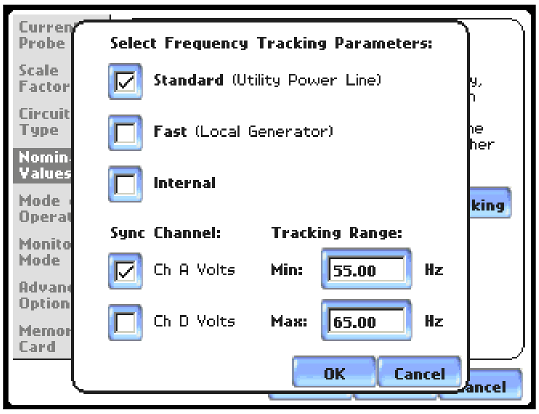


Figure 38: PX5 440 – Wizard screen 3

5 Fundamental Design Considerations

This chapter highlights the fundamental considerations that should form the basis of any solution to the problem.

5.1 The User Profiles

The end-users of Thor are mostly power quality consultants, and energy consultants. They are highly trained, specialist electrical engineers that have the skills necessary to put the instrument to good use. Benchmark imagines future power quality analyzers could be made more accessible to lesser-trained electrical technicians by implementing job assistance features. This would enable Fluke to expand its customer base.

Generalizations of the findings of the interview, conversations with employees of Benchmark and Fluke, and common sense assumptions by the author, have led to the establishment of two user profiles for the new user interface design. These are presented in the table below. The new design should primarily consider the user profile of the “regular electrical technicians”.

User characteristics	**New user interface users’ characteristics**	
	Power quality and energy consultants (existing user group)	**Regular electrical technicians (new user group)**
Age	Range in age from about 30 to 60 years	Will range in age from about 25 to 60 years
Sex	Are mostly male	Will mostly be male
Educational background	Generally have had a college education	Will generally have had a community/junior college education
	Generally have extensive experience in the field of electrical engineering	Will generally have some experience in the field of electrical engineering
	Have specialist knowledge of low voltage power systems, power factor and harmonic disturbance issues, and power factor correction equipment	Will have familiarity with low voltage power systems, power factor and harmonic disturbance issues, and power factor correction equipment
Physical limitations	Have some physical limitations in relation to the use of hands, due to the wearing of electrical gloves	Will have some physical limitations in relation to the use of hands, due to the wearing of electrical gloves
Tool use	Make regular use of basic electrical tools	Will generally have had some prior experience using basic electrical tools
	Make regular use of a power quality analyzer	Will generally have had no prior experience using a power quality analyzer
	Use a limited number of the features provided by the analyzer	

	Use special computer software to perform calculations that are part of their power factor analysis	
Attitude	Are traditionalistic with regard to work practices; may hesitate to embrace new technologies	Will be new to their jobs: will probably be more accepting of new technologies
	May be somewhat distrustful of comprehensive 'auto' functions	Will probably place confidence in comprehensive 'auto' functions
	May feel threatened by new technologies that aim to simplify the work process (fear of being made redundant)	Will probably feel bolstered by new technologies that aim to simplify the work process
Motivation	Will probably be motivated by job productivity considerations to use new features in the Analyzer	Will probably be motivated by general job performance considerations to use new features in the Analyzer

5.2 Restrictions on the Hardware

Benchmark wishes for the design to become viable within five years from now. Important considerations that arise from this are the size and weight restrictions of the Analyzer instrumentation five years from now. The instrumentation is not expected to change dramatically in five years. Thus, a decision was made that the new interface design should fit an analyzer that has approximately the same frontal dimensions as Thor, and should fit an analyzer that weighs about 1.5 kg.

5.3 Nielsen's Usability Heuristics

It is important that the new user interface design conforms to general principles of user interface design. Jakob Nielsen has devised ten *heuristics*, or "rules of thumb", that are frequently used to evaluate the usability of user interfaces (Nielsen & Mack, 1994). They can also function as guidelines in the design of user interfaces. In the next chapter they will form the basis for the usability requirements.

The heuristics as published by Nielsen are as follows:

1. *Visibility of system status.*
   The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
2. *Match between system and the real world.*
   The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
3. *User control and freedom.*

Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

4. *Consistency and standards.*
   Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.

5. *Error prevention.*
   Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.

6. *Recognition rather than recall.*
   Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

7. *Flexibility and efficiency of use.*
   Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

8. *Aesthetic and minimalist design.*
   Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

9. *Help users recognize, diagnose, and recover from errors.*
   Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

10. *Help and documentation.*
    Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

5.4 Touch screen-specific Guidelines

The following guidelines, derived from multiple sources, refer specifically to the design of touch screen user interfaces, and are used to supplement Nielsen's Heuristics in the next chapter:

1. *Use sufficiently sized buttons.*
   The ideal size of hard buttons used with industrial gloves is 31 mm x 31 mm (Wesley, Peggy, & Barry, 1992). The author of this report assumes that the active areas of touch screen buttons for gloved use should have at least this size.

2. *Provide immediate feedback upon reception of touch screen user input.*
   Feedback acknowledges the user’s actions and assures them that processing is occurring. Users expect immediate feedback when they operate a control (Apple, Inc., 2011).

3. *Use bright background colors.*
   Bright background colors hide fingerprints and reduce glare (Waloszek, 2000).

4. *Be aware of screen coverage.*
   The hand or finger of the user may obscure parts of the screen during operation (Waloszek, 2000). Navigation buttons may best be placed at the bottom of the screen area.

5. *Prefer constrained controls.*
   Constrained controls like lists and sliders reduce the need for text input, which can be cumbersome on a touch screen (Microsoft, n.d.).

6. *Provide appropriate default values.*
   Selecting the safest and most secure options by default may prevent loss of data or unwanted system access. Selecting the most likely or convenient option may eliminate unnecessary interaction (Microsoft, n.d.).

6 List of Requirements

Resulting from the findings of chapter 4 and 5, the following are the requirements for the design of a future Fluke Power Quality Analyzer's touch screen user interface that facilitates job assistance.

Requirements for the Job Assistance Features

1. **The interface should support job assistance features that decrease the difficulty of power factor analysis (to ordinary electrical technicians), while preserving its compass.**
   - 1.1. The interface should support an expert system that places minimal demands on the user's knowledge of power factor analysis, and guides the user through the entire power factor analysis process, step by step.
     - 1.1.1. The analyzer should perform all the calculations that are involved in power factor analysis.
     - 1.1.2. The analyzer should decide when, where, and for how long to take measurements of a power system.
     - 1.1.3. The analyzer should interpret the measuring results and recommend a solution to a power factor problem.
   - 1.2. The interface should support an expert system that proposes a full and optimal solution to a power factor problem.
     - 1.2.1. The analyzer should propose an optimal distribution of capacitor banks in a power system.
     - 1.2.2. The analyzer should propose the placement of harmonic filters in a power system, when necessary.
     - 1.2.3. The analyzer should outline the financial savings that are made by implementing a solution.

2. **The interface should support job assistance features that increase the efficiency and convenience of power factor analysis (to experienced power factor engineers).**
   - 2.1. The analyzer should reduce the time it takes the user to complete a power factor analysis.
   - 2.2. The analyzer should not burden the user with tedious manual input of data of a customer's power system.
     - 2.2.1. The analyzer should be able to load and interpret a one-line diagram of a power system.
   - 2.3. The analyzer should be able to access up-to-date product and price information on power factor correction equipment at the customer's location.
   - 2.4. The analyzer should automatically prepare an analysis report for sharing with the customer at the customer's location.
   - 2.5. The analyzer should be able to save customer information, measurement data and analysis reports on an internal memory for future reference.

Requirements for the Touch Screen User Interface

1. **The user interface design should ensure user accessibility.**
   1.1. The interface should be operable while the analyzer is held in one hand.
   1.2. The interface should be operable using Class 0 (1000 V) high voltage electrical gloves.
      1.2.1. Specification: Active areas of finger-operated touch screen buttons should be at least 31 mm x 31 mm in size, and at least 3 mm apart.
   1.3. The interface should be interpretable while dust and oily smudges cover the touch screen.
      1.3.1. All screen elements should have enough visual clarity. They should be large, simple, and of sufficient contrast.
   1.4. The interface should be interpretable to users who are totally or partially color blind.
      1.4.1. Gray-scale versions of screen elements should be fully understandable.

2. **The user interface design should ensure proper usability: it should be in accordance with Nielsen's usability heuristics.**
   2.1. Heuristic 1: The interface should keep the user informed.
      2.1.1. The user should be informed of what step he is currently in and what steps will follow next.
      2.1.2. Immediate and sufficient feedback should be provided upon reception of touch screen user input.
      2.1.3. Touch areas for frequently used commands should mostly be located at the right and bottom side of the touch screen. Such placement will minimize screen view obstruction for right-handed users—the majority of users—during operation of the touch screen.
   2.2. Heuristic 2: The interface should speak the user's language.
      2.2.1. Words, phrases and concepts should be used that are understood by power factor technicians.
   2.3. Heuristic 3: The interface should allow for user control and freedom.
      2.3.1. Clearly marked 'exit' and 'undo' buttons should be present throughout the interface.
   2.4. Heuristic 4: The interface should be consistent and follow standards.
      2.4.1. The controls for different features should be presented in a consistent manner, so the user can locate them easily.
      2.4.2. Commands should work the same way in different contexts.
      2.4.3. The interface should be instantly clear to Thor users and incorporate essential aspects of the Thor interface.
         2.4.3.1. The general menu structure of the Thor interface should be used.
         2.4.3.2. The system status indicators of the Thor interface should be used.
         2.4.3.3. The color coding system of the Thor interface should be used.
         2.4.3.4. Screens presenting measuring results should be akin to Thor Waveform, Phasor, Bar Graph, Meter, or Trend screens.
   2.5. Heuristic 5: The interface should prevent the occurrence of errors.
      2.5.1. A confirmation option should be presented to users before they commit to an action that is prone to errors.
   2.6. Heuristic 6: The interface should place minimal demands on the user's memory.

2.6.1. Objects, actions, and options should be visible.
2.6.2. Information should not have to be remembered from one part of a dialogue to another.
2.6.3. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

2.7. Heuristic 7: The interface should be flexible and efficient in use.

2.7.1. Repetitive actions should be automatable by the user.
2.7.2. Frequently used commands should be located on the lower levels of a menu hierarchy.

2.8. Heuristic 8: The interface should be aesthetic and minimalist.

2.8.1. Dialogues should not contain irrelevant or rarely needed information.

2.9. Heuristic 9: The interface should help the user recognize, diagnose, and recover from errors.

2.9.1. Error messages should indicate the problem and suggest a solution in the language of electrical technicians.

2.10. Heuristic 10: The interface should provide help and documentation.

2.10.1. Assistance should be easy to locate, to the point, and list concrete steps to carry out.

3. **The user interface design should ensure user safety.**

3.1. The interface should not discourage the user to wear suitable electrical gloves during operation of the analyzer in hazardous circumstances.
3.2. The interface should not induce strain on the user's hands and wrists during operation of the analyzer.
3.3. Solutions for the prevention of strain on the user's hands and wrists should not involve the implementation of a neck strap.

4. The user interface design should fit within Fluke's brand image: it should be in accordance with the standards outlined in the Fluke Corporate Industrial Design Standards Manual.

4.1. The interface should conform to the Fluke product coloring standard.
4.2. The interface should conform to the Fluke standards of typography and use of graphics.

5. The user interface design should work within the restrictions set on the hardware.

5.1. The interface should fit an analyzer that weighs about 1.5 kg.
5.2. The interface should fit an analyzer that has approximately the same frontal dimensions as Thor.

5.2.1. <u>Specification:</u> The maximum dimensions for the touch screen are about 240 mm x 150 mm, in case of a tallscreen, or 150 mm x 240 mm, in case of a widescreen.

7 Design concepts

7.1 Concept 1: “Power Touch”

The first concept for a new user interface is called “Power Touch” (Fig. 37). This concept was created early in the project.

This concept implements a wide screen LCD, about 8 inches in diameter. Naturally, the display is touch-enabled. Inputs are located at the top of the instrument. It is designed to be held only by the user’s left hand. The right hand is used solely for touch screen input. This decision was made because operating the device while holding it with both hands was not deemed practical: whatever screen format used, one cannot easily reach the middle of the screen with both thumbs. The instrument offers a nicely shaped grip at its left side for comfortable holding. Though not visible in the images, a hand strap is also employed in the concept.

The concept features an expert system and considers three distinct phases in the power factor analysis process:

- Phase 1: Setup (Fig. 37)
- Phase 2: Measure (Fig. 38)
- Phase 3: Solutions (Fig. 39)

It guides the user through each phase in a series of steps. First, the user loads an electronic version of a client’s one-line diagram into the device. He also states the purpose of his investigation. Based mainly on the diagram, the power factor expert system subsequently decides when, where, and for how long to monitor at different locations of the client’s power system. The user is guided in the measurement taking process. Finally, results are presented for the user to review. The results are a complete solution

The screens are fairly simple by design. There are five ever-present function keys that correspond to Thor’s soft keys. They are stacked on top of each other against right edge of the screen in order to prevent screen view obstruction while using them, and are sufficiently large to be operated by a user wearing electrical safety gloves. A stylus can also be used. A swiping gesture is used to scroll through the one-line diagram.

The expert system is in a rudimentary form and should be further refined.

The proposed method of holding the device is problematic. Firstly, the interface is designed with only right-handed users in mind. Secondly, when the unit is operated by the user, its center of gravity is situated about 10 cm away from the user’s hand on the horizontal plane. Since the unit weighs 1.5 kg, this induces a large amount of strain on the user’s left wrist in particular. A neck strap cannot be implemented to ease the burden since it would violate a safety requirement.

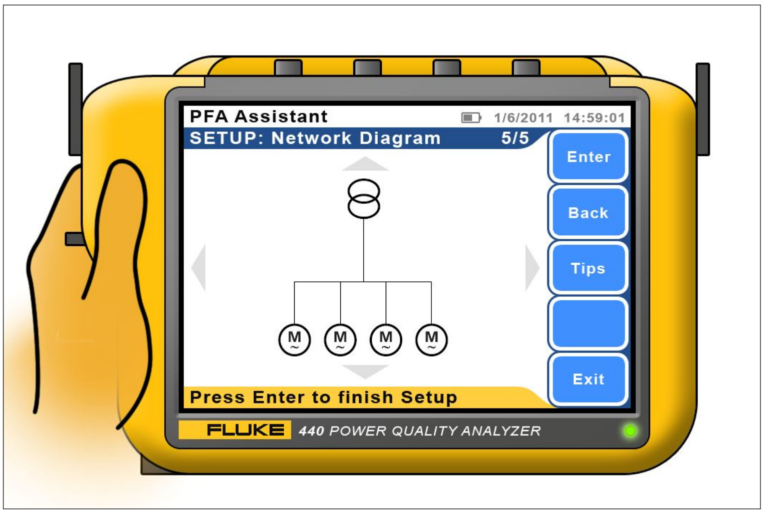


Figure 37: Setup

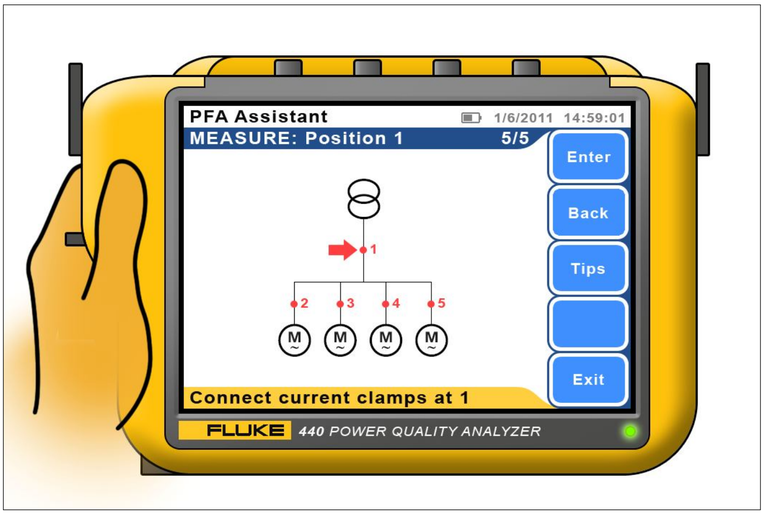


Figure 38: Measure

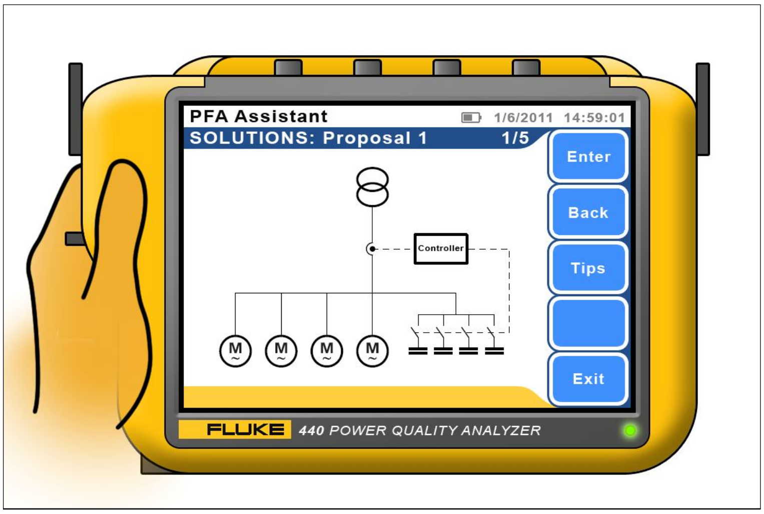


Figure 39: Solutions

7.2 Concept 2: “Power Tab”

The first concept for the design of a future Fluke Power Quality Analyzer’s touch screen user interface is called “Power Touch” (Fig. 40; Fig. 41). It is more of a hardware concept.

This concept was created primarily with the aim of correcting the issue of wrist strain in the first concept.

It consists of two parts:

- A base station that contains all of the device’s measuring hardware.
- A separate remote display that is wirelessly connected to the base station.

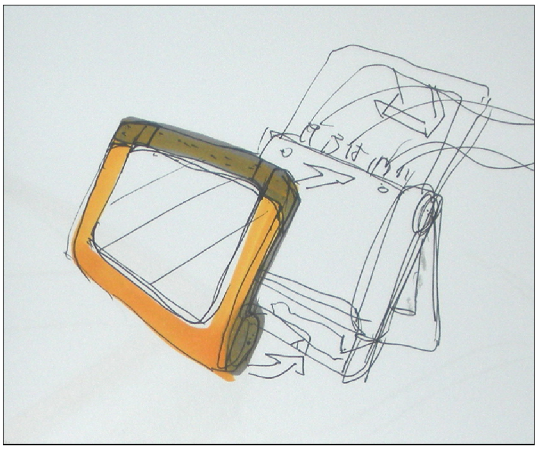


Figure 40: The “Power Tab”

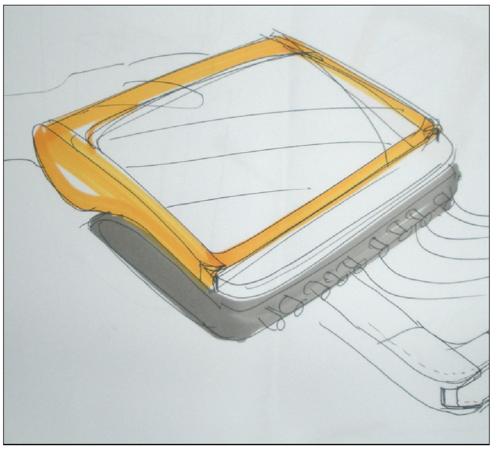


Figure 41: The “Power Tab”

The design focus in this concept was on the remote display.

The remote display can be physically attached to the base station so a single unit is formed. The remote display has about the same size as a 10 inch tablet.

The remote display is used to control the base station from a suitable distance and order it to take measurements. In section 4.3 it was presented that measurement locations are often in cramped and poorly accessible spaces in European-style power distribution panels. The remote display may alleviate this problem.

A major advantage of this concept compared to the first concept is that the user never has to support the entire weight of the analyzer during operation. The remote display may about 500 grams. This weight is considered small enough not to induce strain on the user’s wrist, whichever way it is grabbed.

The remote display has a battery pack located at its left side. At this location it is thicker. This is a convenient place to grab the remote display. Left-hand users can also use it in the most comfortable manner, by rotation the device 180 degrees, so the grabbing location is at the right. The screen of the remote display automatically adjusts to the new orientation.

The remote display can be used in landscape or portrait mode (Fig. 42; Fig. 43). Both have advantages when it comes to displaying measurement data.

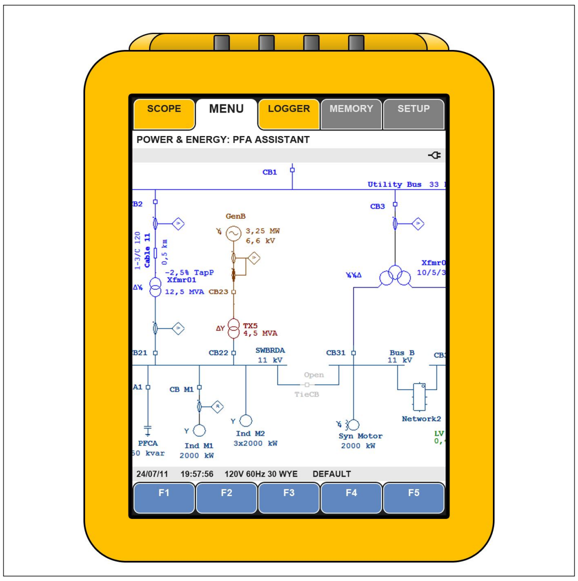


Figure 42: Portrait mode

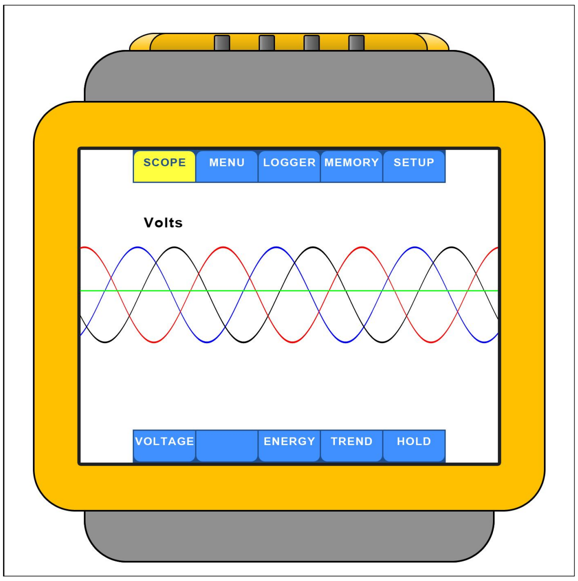


Figure 43: Landscape mode

8 Final Design Concept

The “Power Tab” concept was chosen as the final concept to further elaborate on.

The focus in this final design concept lay on the graphical user interface and job assistance options.

A casing was also designed (Fig. 44; Fig. 45; Fig. 46).

A setup assistant was made for power factor analysis that relies on a power factor expert system.

The interface is intended to work with gloved hands.

Only tapping and swiping gestures are implemented.

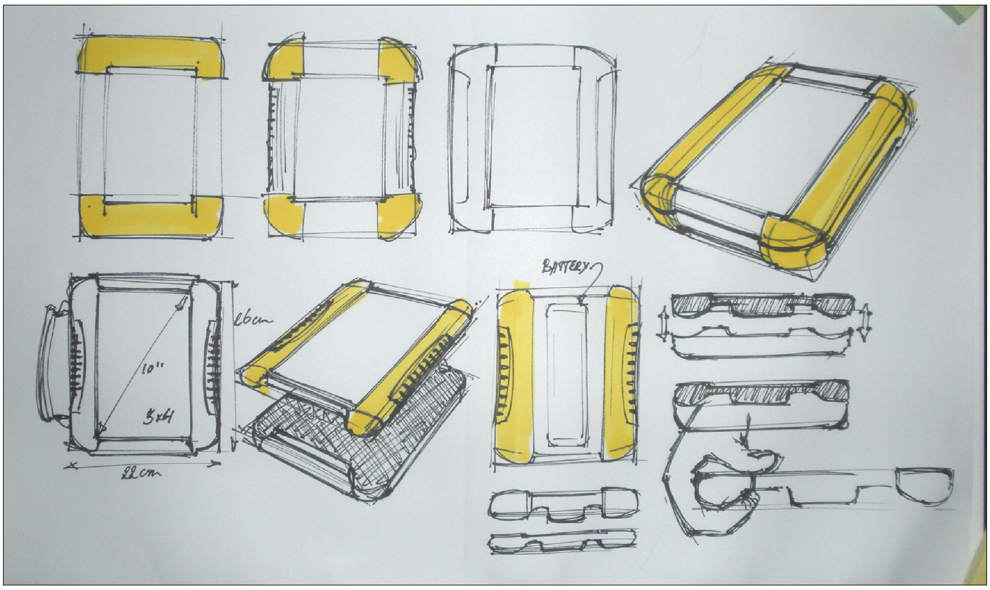


Figure 44: Sketches for the case design

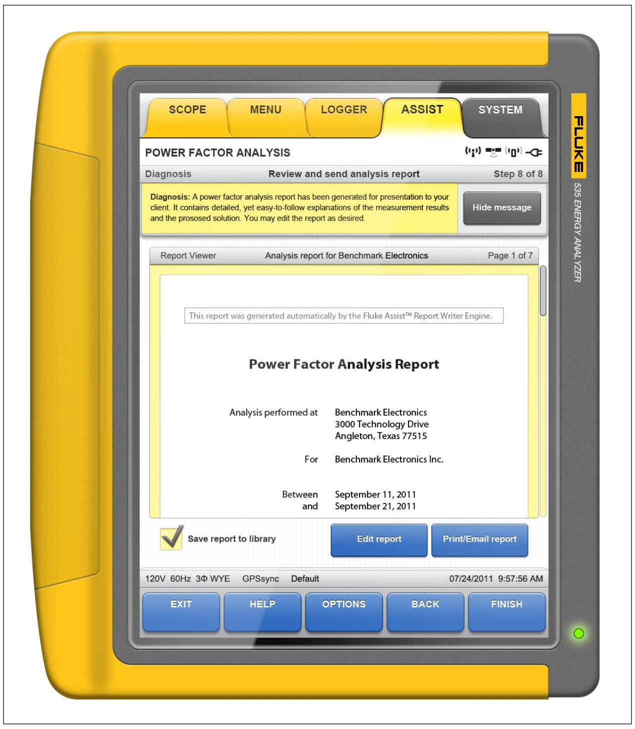


Figure 45: A realistic presentation of the concept

Figure 46: Using the concept

8.1 Process

The design guides the user through eight well-defined steps to perform a power factor analysis:

- Main menu (Fig. xx)
  The user can choose from five menu options. Tap “start new analysis job” to launch a new power factor investigation. Tap “load analysis job” to resume an unfinished investigation. Tap “load analysis job set up” to start from an existing analysis setup.

- Step 1 (Fig. xx)
  The user is asked to specify the purpose of his power factor investigation, and enter basic client information for convenient cataloging of the diagnostic results.

- Step 2 (Fig. xx)
  The user is asked to fill in the figures from his client’s monthly utility invoice. If his client’s power consumption varies throughout the year, he is advised to select an invoice from the month in which it peaks.

- Step 3 (Fig. xx)
  The user is asked to provide a one-line diagram of his client’s power system in a supported file format. The file can be loaded from an external source through the Analyzer’s mini-USB port, or from the diagram library if it has previously been saved there.

- Step 4 (Fig. xx)

The user is asked to make sure that the one-line diagram is an accurate representation of his client's present power system. He can edit various system parameters by tapping the symbols in the diagram. Changes that are saved will affect the proceeding analysis.

- Step 5 (Fig. xx)
  The user is asked to take measurements of your his power system at the locations prescribed in the table. He is reminded to properly connect the Analyzer prior to measurement. He may leave the Analyzer unattended while measurements are performed.

- Step 6 (Fig. xx)
  The Analyzer indicates measurement values of key parameters at four measurement locations. Serious conditions are highlighted by a red background and a warning symbol. Detailed measuring results can be viewed for each location by tapping "view details".

- Step 7 (Fig. xx)
  A power factor solution is proposed involving the placement of capacitor banks and harmonic filter bank at specific locations in the power system. Annual savings and equipment cost estimates are provided.

- Step 8 (Fig. xx)
  A power factor analysis report is generated for presentation to the user's client. It contains detailed, yet easy-to-follow explanations of the measuring results and the proposed solution. You may edit the report as desired.

8.2 Screen Layout

(See page 57 for the names and locations of the screen elements)

- Menu Tabs
  Job assistance functionality is located under the "Assist" tab. "SCOPE", "MENU" and "LOGGER" tabs correspond with the main menu options.
- Mode title bar
- Status icons
- Step title bar
- Message pane
- Main area
- Active selection
- Touch keyboard
- Status line
- Function keys

8.3 Interface sequence

An interface sequence has been created. Please, see Appendix D.

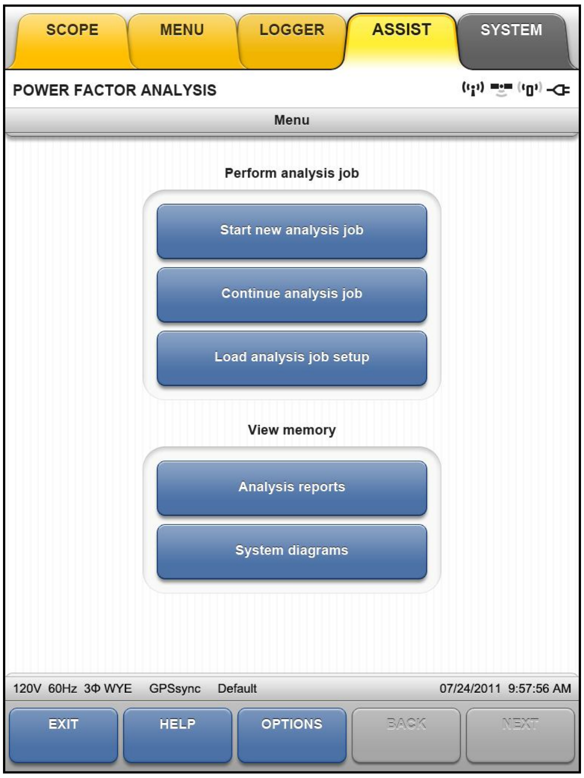


Figure xx: Main Menu

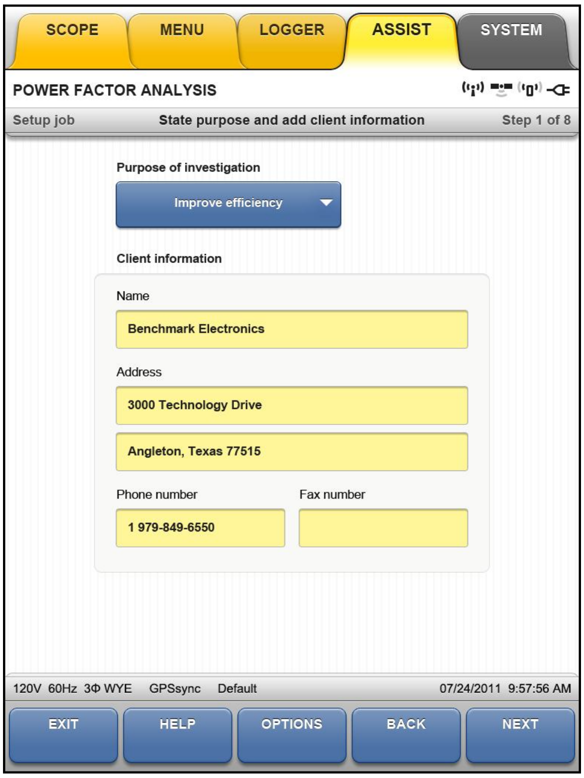


Figure xx: Step 1

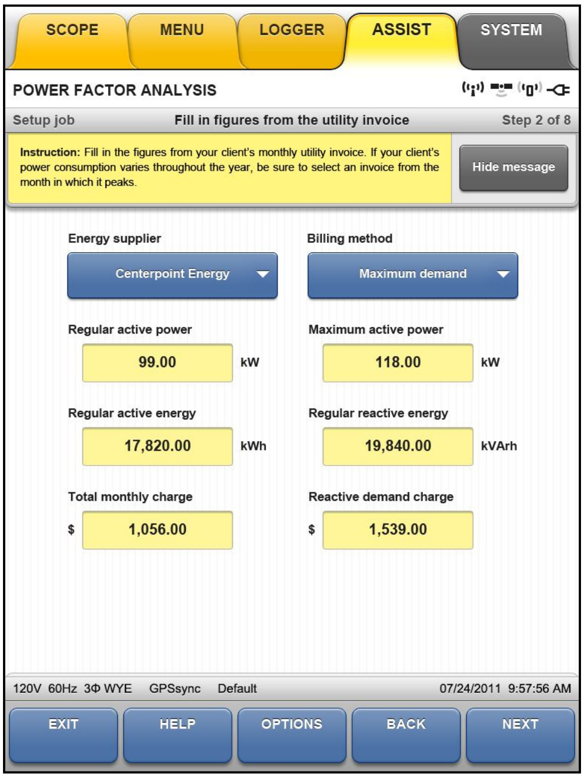


Figure xx: Step 2

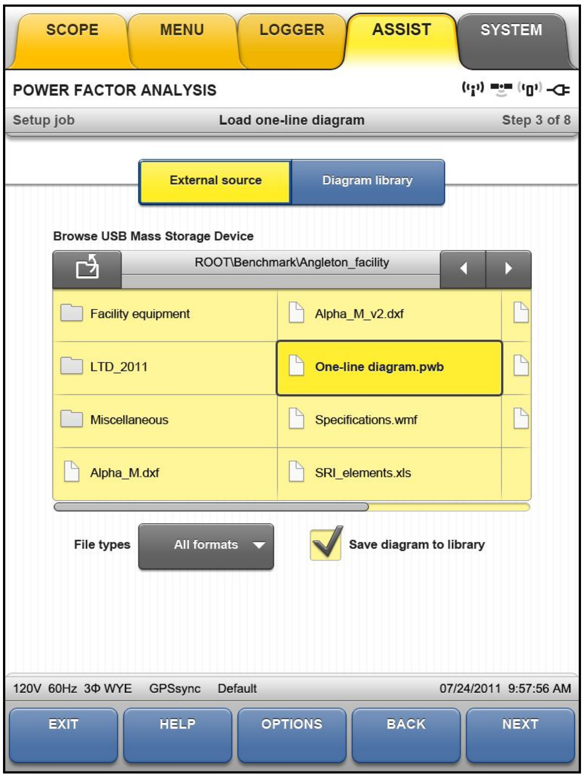


Figure xx: Step 3

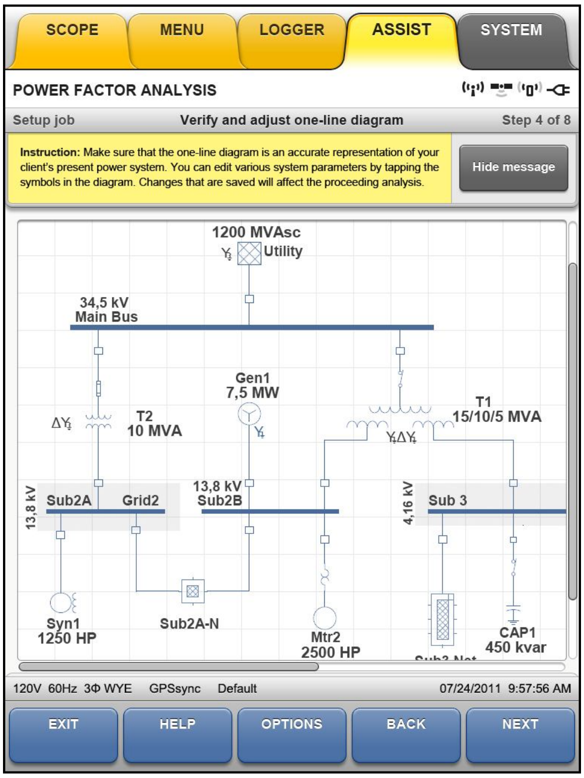


Figure xx: Step 4

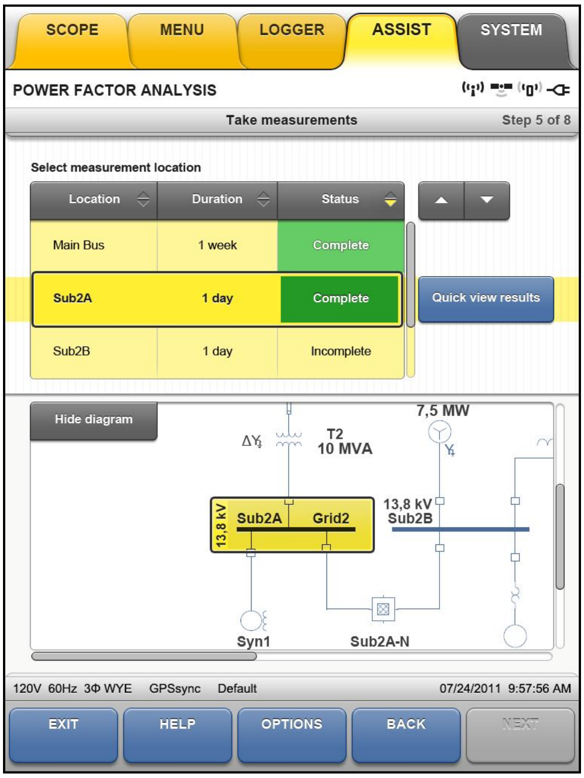


Figure xx: Step 5

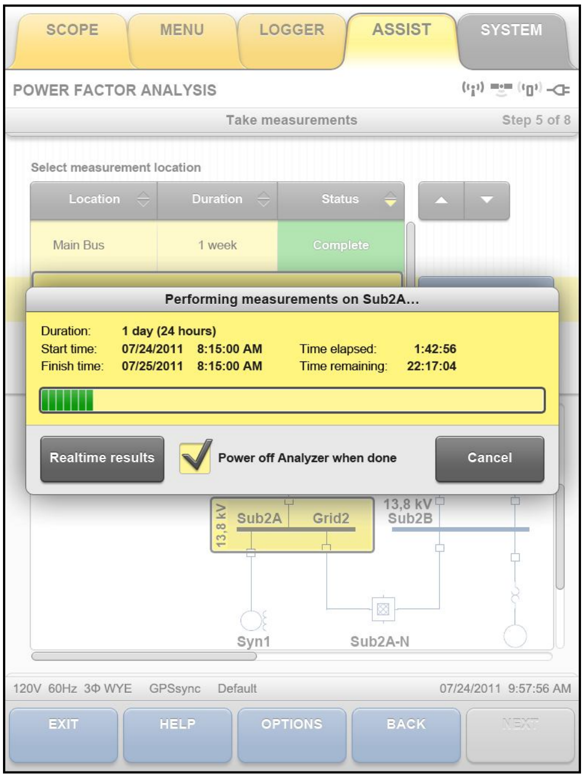


Figure xx: Step 5

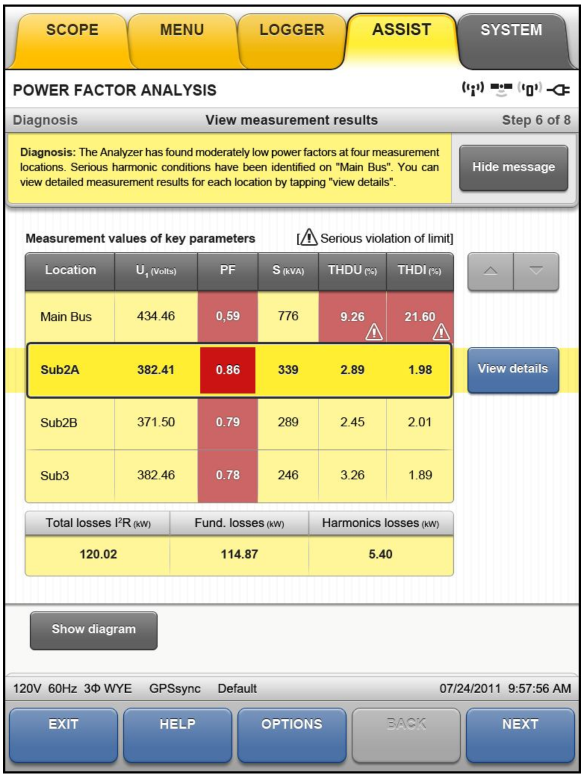


Figure xx: Step 6

Figure xx: Step 7

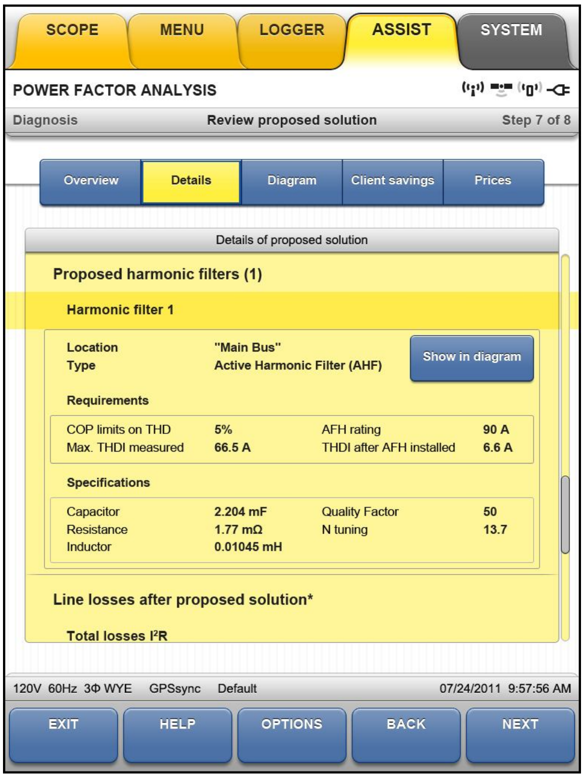


Figure xx: Step 7

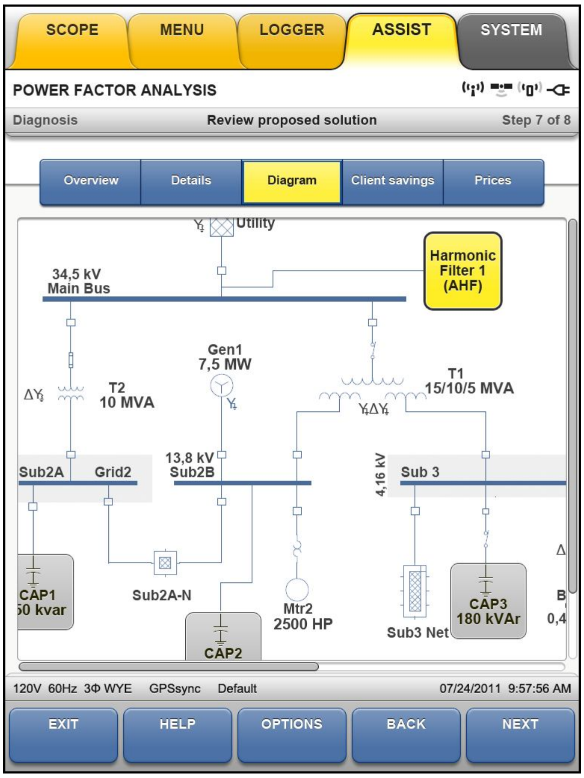


Figure xx: Step 7

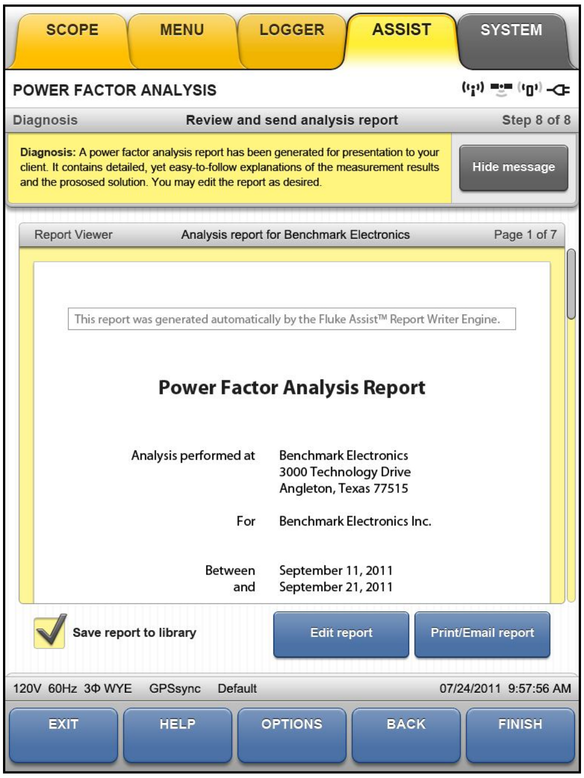
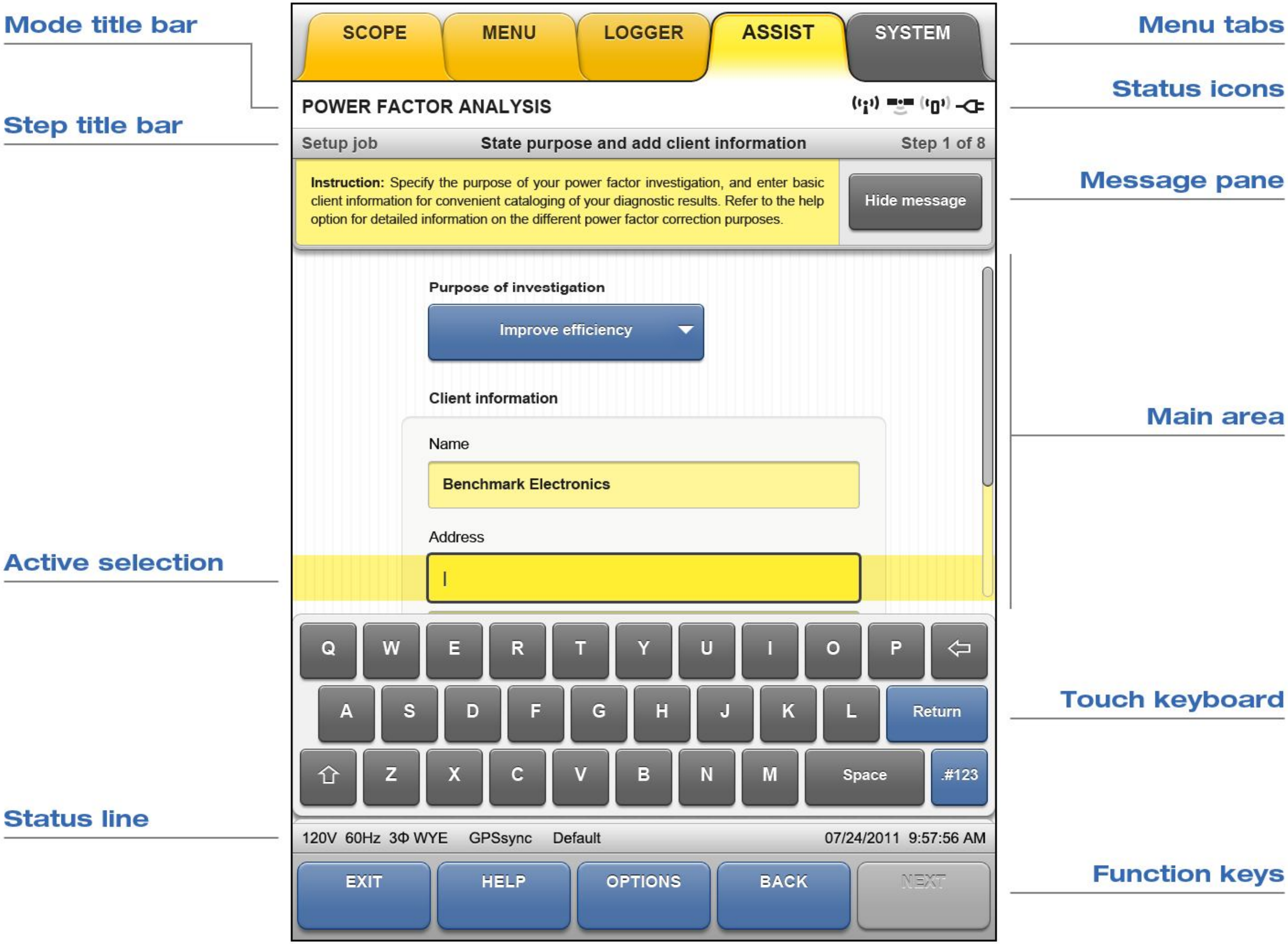
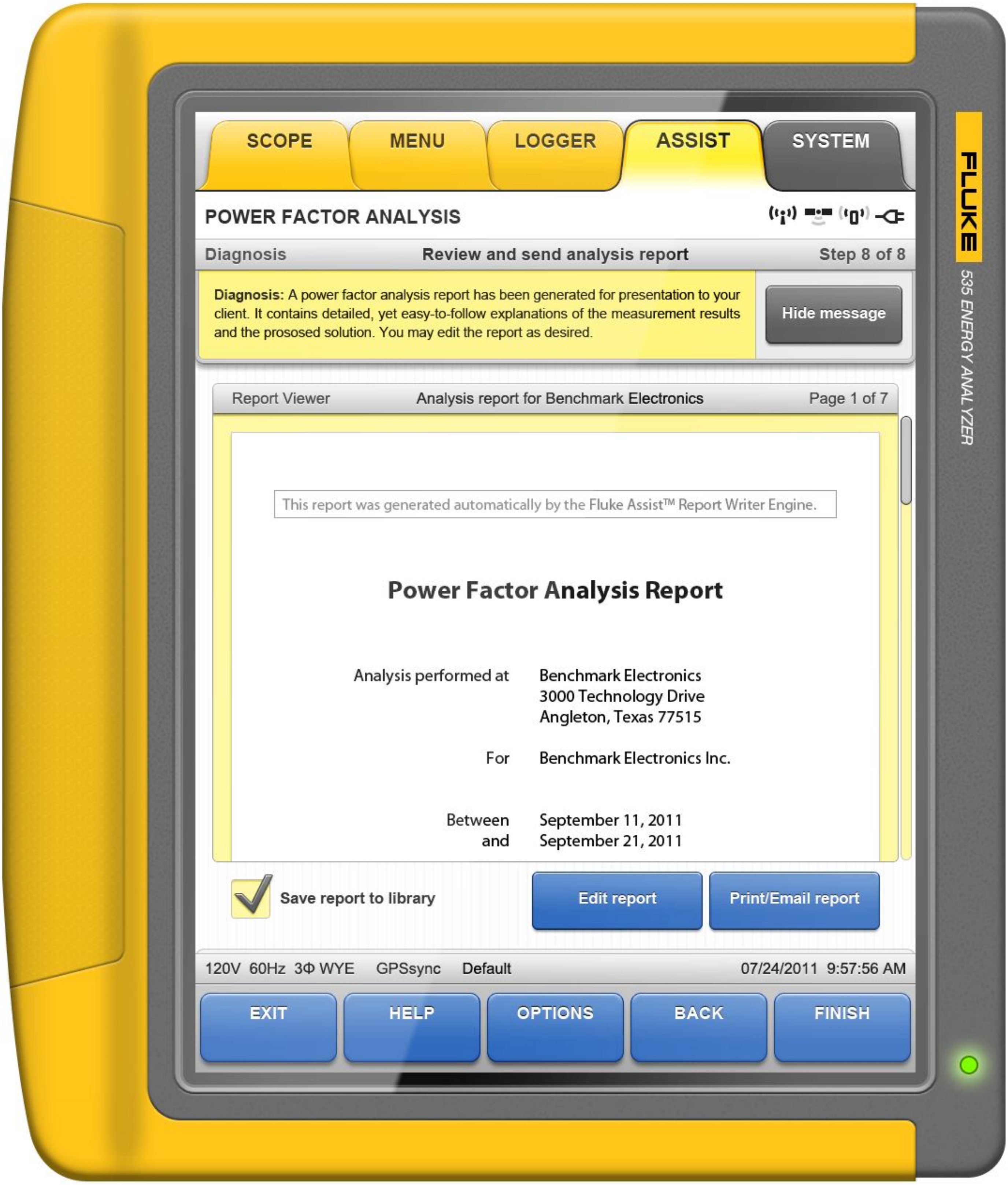


Figure xx: Step 8



Mode title bar
Step title bar
Active selection
Status line
Menu tabs
Status icons
Message pane
Main area
Touch keyboard
Function keys
SCOPE
MENU
LOGGER
ASSIST
SYSTEM
POWER FACTOR ANALYSIS
Setup job
State purpose and add client information
Step 1 of 8
Instruction: Specify the purpose of your power factor investigation, and enter basic client information for convenient cataloging of your diagnostic results. Refer to the help option for detailed information on the different power factor correction purposes.
Hide message
Purpose of investigation
Improve efficiency
Client information
Name
Benchmark Electronics
Address
Return
Space
.#123
120V 60Hz 3Φ WYE GPSsync Default 07/24/2011 9:57:56 AM
EXIT
HELP
OPTIONS
BACK
NEXT


SCOPE
MENU
LOGGER
ASSIST
SYSTEM
POWER FACTOR ANALYSIS
Diagnosis
Review and send analysis report
Step 8 of 8
Diagnosis: A power factor analysis report has been generated for presentation to your client. It contains detailed, yet easy-to-follow explanations of the measurement results and the prososed solution. You may edit the report as desired.
Hide message
Report Viewer
Analysis report for Benchmark Electronics
Page 1 of 7
This report was generated automatically by the Fluke Assist™ Report Writer Engine.
Power Factor Analysis Report
Analysis performed at
Benchmark Electronics
3000 Technology Drive
Angleton, Texas 77515
For
Benchmark Electronics Inc.
Between
September 11, 2011
and
September 21, 2011
Save report to library
Edit report
Print/Email report
120V 60Hz 3Φ WYE
GPSsync
Default
07/24/2011 9:57:56 AM
EXIT
HELP
OPTIONS
BACK
FINISH
FLUKE
535 ENERGY ANALYZER

9 Requirements Verification

The Power Tab user interface has been evaluated using the requirements of chapter 6. Using his best judgment, the author has tried to establish for every requirement if it is met by the design.

Overall, the design appears to fit the requirements quite well. It significantly decreases the difficulty and increases the convenience of power factor analysis. Furthermore, it is accessible and usable; it has regard for user safety; it conforms to Fluke's brand image; and it works within the restrictions placed on the hardware.

The following issues have been uncovered:

- The design does not sufficiently inform the user about the analysis procedure and his progress.
- The design does not have an easy option to show the message pane again after it is has been hidden.
- The design has little similarity with the user interface of Thor. Thor users will have to adapt.

The following explains for each single requirement if it is met by the design:

Requirements for the Job Assistance Features

1.1.1.	*The analyzer should perform all the calculations that are involved in power factor analysis.* **Requirement met:** The design requests the user to provide all the necessary information for the analysis—the client's goal, his utility billing figures and his power system diagram—and performs all the calculations by itself. The user's expertise is only called upon to troubleshoot an outlandish and erroneous analysis result.
1.1.2.	*The analyzer should decide when, where, and for how long to take measurements of a power system.* **Requirement met:** The design guides the user through the entire measurement taking process in step 5.
1.1.3.	*The analyzer should interpret the measuring results and recommend a solution to a power factor problem.* **Requirement met:** The design interprets the measuring results and recommends a solution in step 7.
1.2.1.	*The analyzer should propose an optimal distribution of capacitor banks in a power system.* **Requirement met:** The design determines the best configuration of capacitor banks in step 7.
1.2.2.	*The analyzer should propose the placement of harmonic filters in a power system, when necessary.* **Requirement met:** The design may propose the placement of harmonic filters in step 7.
1.2.3.	*The analyzer should outline the financial savings that are made by implementing a solution.* **Requirement met:** The design features client savings estimates for the proposed solution in the "savings" tab of step 7.

2.1.	*The analyzer should reduce the time it takes the user to complete a power factor analysis.* **Unable to check:** The design's eight step method is intended to streamline the analysis process. A user test is necessary to confirm that it really saves time.
2.2.1.	*The analyzer should be able to load and interpret a one-line diagram of a power system.* **Requirement met:** The design requires the user to supply a one-line diagram, which it interprets by itself.
2.3.	*The analyzer should be able to access up-to-date product and price information on power factor correction equipment at the customer's location.* **Requirement met:** The design features product and price information on power factor correction equipment in the "prices" tab of step 7.
2.4.	*The analyzer should automatically prepare an analysis report for sharing with the customer at the customer's location.* **Requirement met:** The design presents to the user an analysis report that can be saved, edited, printed and sent via email.
2.5.	*The analyzer should be able to save customer information, measurement data and analysis reports on an internal memory for future reference.* **Requirement met:** The design optionally saves one-line diagrams and analysis reports to special internal libraries and uses client information to conveniently catalog saved analysis data.

Requirements for the Touch Screen User Interface

1.1.	*The interface should be operable while the analyzer is held in one hand.* **Requirement met:** In the design, the remote display can be operated while it is held in one hand. The remote display offers full control over the instrumentation of the base station.
1.2.1.	*Specification: Active areas of finger-operated touch screen buttons should be at least 31 mm x 31 mm in size.* **Requirement partially met:** The active areas of many touch screen buttons in the design are larger than 31 mm x 31 mm in size. However, the keyboard keys—the letter keys in particular—are small and tightly packed; necessarily, the sizes of their active areas are much smaller than prescribed. The first step in the design is best carried out while not wearing gloves.
1.3.1.	*All screen elements should have enough visual clarity. They should be large, simple, and of sufficient contrast.* **Requirement met:** All Tabs, buttons, text and selections are easily discriminated.
1.4.1.	*Gray-scale versions of screen elements should be fully understandable.* **Requirement met:** The design employs redundant coding. Selections have a bright yellow background as well as a thick black border. Red and green are never used as functional colors at the same time.
	Nielsen's Heuristic 1: The interface should keep the user informed.
2.1.1.	*The user should be informed of what step he is currently in and what steps will follow next.* **Requirement partially met:** The design provides the title of the current step the user is in. By

	showing the number of steps that comprise the analysis procedure, and the number steps that have been completed, it informs the user of his progress in a rudimentary fashion. It should maybe list by name all steps that have been completed and all that are yet to be completed.
2.1.2.	*Immediate and sufficient feedback should be provided upon reception of touch screen user input.* **Requirement met:** In the design, selected items are highlighted in yellow. Planned features that indicate when a button has been tapped have not yet been added to the design.
2.1.3.	*Touch areas for frequently used commands should mostly be located at the right and bottom side of the touch screen. Such placement will minimize screen view obstruction for right-handed users—the majority of users—during operation of the touch screen.* **Requirement met:** In the design, the function keys are the most frequently used commands. They are located at the bottom of the touch screen.
	Nielsen's Heuristic 2: The interface should speak the user's language.
2.2.1.	*Words, phrases and concepts should be used that are understood by power factor technicians.* **Requirement met:** In its overview screens, the design uses moderately advanced electrical terminology that is assumed to be understood by power factor technicians. This terminology includes terms such as PF, V1, THD-U and THD-I. Power factor technicians are expected to be able to interpret a one-line diagram.
	Nielsen's Heuristic 3: The interface should allow for user control and freedom.
2.3.1.	*Clearly marked 'exit' and 'undo' buttons should be present throughout the interface.* **Requirement met:** Exit and back button are always present in the design. Users may go back one step or exit the Power Factor Analysis application at any moment.
	Nielsen's Heuristic 4: The interface should be consistent and follow standards.
2.4.1.	*The controls for different features should be presented in a consistent manner, so the user can locate them easily.* **Requirement met:** Some commands are available through buttons with text; some through (buttons with) icons or symbols; and some through drop-down lists. The scroll command is generally not accessible through buttons, but through a swiping gesture.
2.4.2.	*Commands should work the same way in different contexts.* **Requirement met:** In the design, tapping a selectable item always triggers a bright yellow selection box; swiping a finger over the screen always means scrolling; et cetera.
2.4.3.1.	*The general menu structure of the Thor interface should be used.* **Requirement partially met, partially unable to check:** The general menu structure of the design is only described in a rudimentary fashion. Each of the first three menu tabs in the design, "Scope", "Menu" and "Logger", has a button equivalent in Donar. The design's "System" tab groups Thor's and Donar's "Setup" and "Memory" buttons.
2.4.3.2.	*The system status indicators of the Thor interface should be used.* **Requirement partially met:** The design employs a number of status indicators that are conceptually and visually identical to Thor's, but it also uses a few new status indicators.
2.4.3.3.	*The color coding system of the Thor interface should be used.* **Requirement partially met:** The design only uses Thor's color coding system for the main

	menu options, “Scope”, “Menu” and “Logger”, and the function keys.
2.4.3.4.	*Screens presenting measuring results should be akin to Thor Waveform, Phasor, Bar Graph, Meter, or Trend screens.* **Requirement not met:** In the design, measuring results are only presented in tabular form. The screens with tables showing measuring results look different from Thor’s meter screens.
	Nielsen’s Heuristic 5: The interface should prevent the occurrence of errors.
2.5.1.	*A confirmation option should be presented to users before they commit to an action that is prone to errors.* **Requirement met:** In step 4, the design asks if (unsaved) modifications the one-line diagram must be saved before continuing to step 5. In step 5, it asks if voltage leads and current clamps are correctly connected before measurement starts.
	Nielsen’s Heuristic 6: The interface should place minimal demands on the user’s memory
2.6.1.	*Objects, actions, and options should be visible.* **Requirement met:** In the design, objects, actions and options are generally visible. In step 4, the file name of the one-line diagram that is being verified should be displayed.
2.6.2.	*Information should not have to be remembered from one part of a dialogue to another.* **Requirement met:** The design does not rely on the user to remember information between steps.
2.6.3.	*Instructions for use of the system should be visible or easily retrievable whenever appropriate.* **Requirement not met:** In the design, a message pane provides instructions at the beginning of each step. A button located on the pane will hide the pane. There is currently no easy option to show the pane again when it is has been hidden.
	Nielsen’s Heuristic 7: The interface should be flexible and efficient in use.
2.7.1.	*Repetitive actions should be automatable by the user.* **Not applicable:** The design has no actions that could become tedious.
2.7.2.	*Frequently used commands should be located on the lower levels of a menu hierarchy.* **Requirement met:** In the design, frequently used commands, such as “next”, “back” and selecting a selectable screen item, are instantly accessible.
	Nielsen’s Heuristic 8: The interface should be aesthetic and minimalist.
2.8.1.	*Dialogues should not contain irrelevant or rarely needed information.* **Requirement met:** In the design, analysis information is provided in two levels of detail. Very specific information about the measuring results and the proposed solution is provided upon request, by tapping a “view details” button.
	Nielsen’s Heuristic 9: The interface should help the user recognize, diagnose, and recover from errors.
2.9.1.	*Error messages should indicate the problem and suggest a solution in the language of electrical technicians.* **Unable to check:** The design has not simulated any errors.
	Heuristic 10: The interface should provide help and documentation.
2.10.1	*Assistance should be easy to locate, to the point, and list concrete steps to carry out.*

	Requirement met: In the design, brief and clearly expressed instructions are provided at the beginning of each step. More comprehensive assistance is available though the “help” function key.
3.1.	*The interface should not discourage the user to wear suitable electrical gloves during operation of the analyzer in hazardous circumstances.* **Requirement met:** During the measurement taking step (step 5) in the design, the user is given no incentive to not wear electrical gloves. The active areas of the touch screen buttons in this step are presumed to be sufficiently large for comfortable operation using electrical gloves.
3.2.	*The interface should not induce strain on the user’s hands and wrists during operation of the analyzer.* **Requirement met:** In the design, the remote display is sufficiently lightweight to be operated while comfortably carried with one hand.
3.3.	*Solutions for the prevention of strain on the user’s hands and wrists should not involve the implementation of a neck strap.* **Requirement met:** A neck strap is not implemented in the design.
4.1.	*The interface should conform to the Fluke product coloring standard.* **Requirement met:** The design employs the distinctive Fluke color palette. Grey, grey-blue and Fluke yellow are used as prescribed by the Fluke Corporate Industrial Design Standards Manual.
4.2.	*The interface should conform to the Fluke standards of typography and use of graphics.* **Requirement met:** The design follows the rules and guidelines for producing a consistent graphic image in the use of the Fluke logo and the product identifier.
5.1.	*The interface should fit an analyzer that weighs about 1.5 kg.* **Requirement met:** Together, the base station and remote display may weigh 1.5 kg in the design.
5.2.1.	<u>*Specification:*</u> *The maximum dimensions for the touch screen are about 240 mm x 150 mm (h x b), in case of a tallscreen, or 150 mm x 240 mm (h x b), in case of a widescreen.* **Requirement met:** A 148 mm x 197 mm touch screen is implemented in the design.

10 Conclusions and Recommendations

10.1 Conclusions

The following conclusions can be drawn:

- A new user interface was created that supports comprehensive job assistance features that help electrical technicians in performing power factor analyses, has touch screen controls and is economically feasible five years from now.
- The design analysis has shown that the creation of a power factor expert system is a viable approach to providing comprehensive job assistance in the power quality analyzer.
- The Power Tab satisfies the requirements to a large extend. It supports job assistance features that significantly decrease the complexity and increase the efficiency and convenience of the user tasks involved in power factor analysis. Moreover, it is accessible and usable; it has regard for user safety; it conforms to Fluke's brand image; and it works within the restrictions placed on the hardware.
- The Power Tab has little similarity with the user interface of Thor. This was to be expected. Thor users will have to adapt to the new design.

10.2 Recommendations

The following recommendations can be made:

- The possibilities of implementing setup assistants and expert systems into the power quality analyzer should be investigated. This could be promising. Benchmark should build more knowledge on how the analyzer is used by its users.
- Expert systems may be beneficial to other kinds of analyses as well. This is also an area of further investigation.
- Fluke is advised to develop setup assistants for difficult applications.
- If touch screen is going to be implemented, the optimal size of touch screen buttons with the use of gloves should be determined through user testing. There is little research available on this subject.
- Fluke is not recommended to implement touch screen in the power quality analyzer if weight and manner of holding the device remain the same.

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Appendix A – Benchmark Electronics

Founded in 1979, Benchmark Electronics is an American multinational electronics company that offers design, manufacturing and fulfillment services—collectively known as *electronics manufacturing services*[9] (EMS). Its customers are mostly *original equipment manufacturers*[10] (OEMs). The company contract designs, manufactures and refurbishes (components for) advanced electronics products that are marketed under other companies' brand names.

Its products fall into five main categories: telecommunication equipment; computing-related products for business enterprises; industrial control equipment; testing and instrumentation products; and medical devices.

Benchmark has a global presence with 20 locations in 10 countries, spread across four continents. The company employs around 10,000 people and is headquartered in Angleton, Texas. Its revenues were $ 2,402.1 million over the 2010 fiscal year (Benchmark Electronics, n.d.).

Benchmark has adopted the following mission statement (Benchmark Electronics, n.d.): "The mission of Benchmark Electronics, Inc. is to maintain a global leadership position in the high technology electronics manufacturing services industry."

The company pursues "long-term relationships with leading OEMs in expanding industries by becoming an integral part of [its] customers' manufacturing operations" (Benchmark Electronics, 2010). It seeks to leverage its advanced technological capabilities and focus on high-end products (Benchmark Electronics, 2010).

Benchmark's business philosophy is described by three concepts (Benchmark Electronics, n.d.):

- Integrity: engaging in honest, ethical and fair dealings inside and outside the company.
- Flexibility: adapting quickly to costumers' needs.
- Execution: working closely with costumers, forming synergetic relationships with them, in order to meet and exceed their expectations.

Three of Benchmark's worldwide locations are Manufacturing & Design Centers, which specialize in new product development. One of these is Benchmark Electronics bv in Almelo, The Netherlands.

This division operates a 132,000 square feet complex facility and employs some 300 people. It serves high technology companies in test and measurement, medical, military, aerospace, semiconductor equipment and industrial markets. Its customers include multi-billion-dollar companies like Siemens and Airbus.

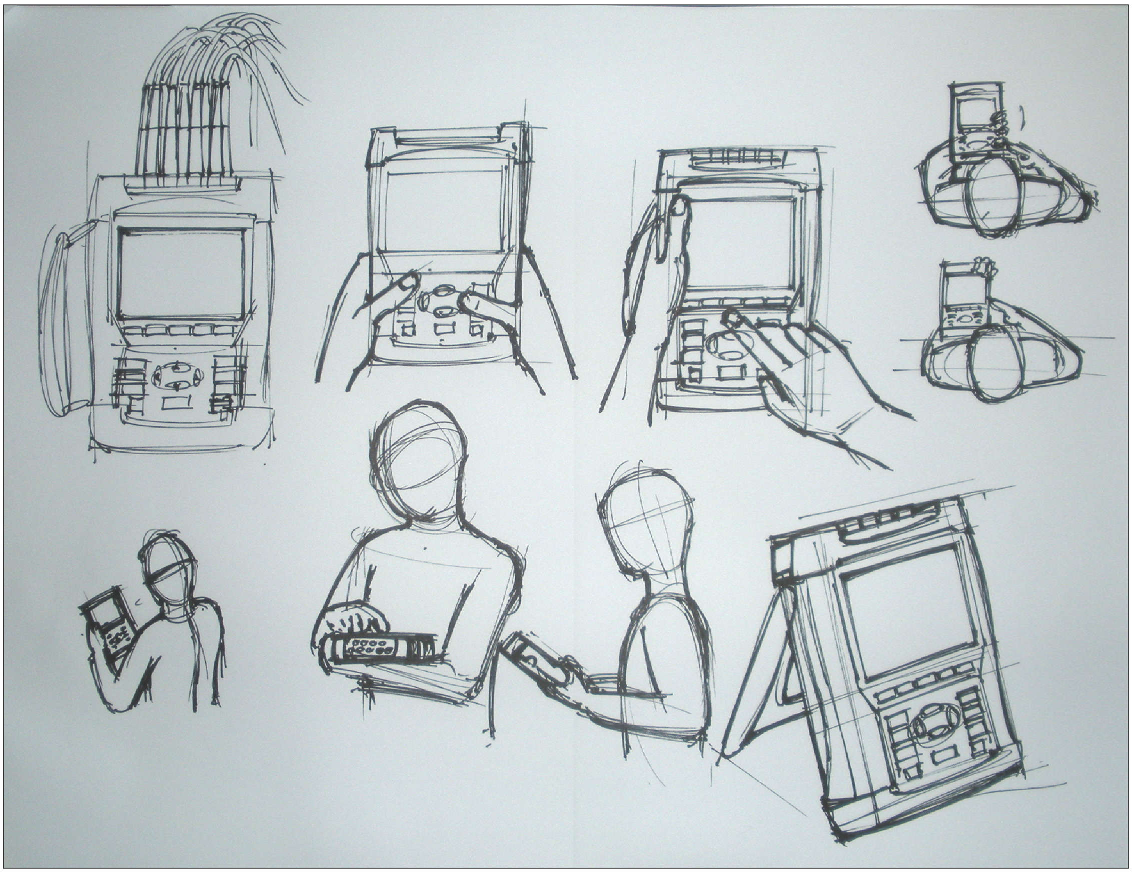
[9] *Electronics manufacturing services* zijn diensten met betrekking tot het ontwerpen, testen, fabriceren, distribueren en repareren van elektronische producten of componenten, die door bedrijven aan *original equipment manufacturers* worden geleverd.

[10] *Original equipment manufacturers* zijn bedrijven die producten of componenten produceren en verkopen aan andere bedrijven die deze onder hun eigen merknaam op de markt brengen.

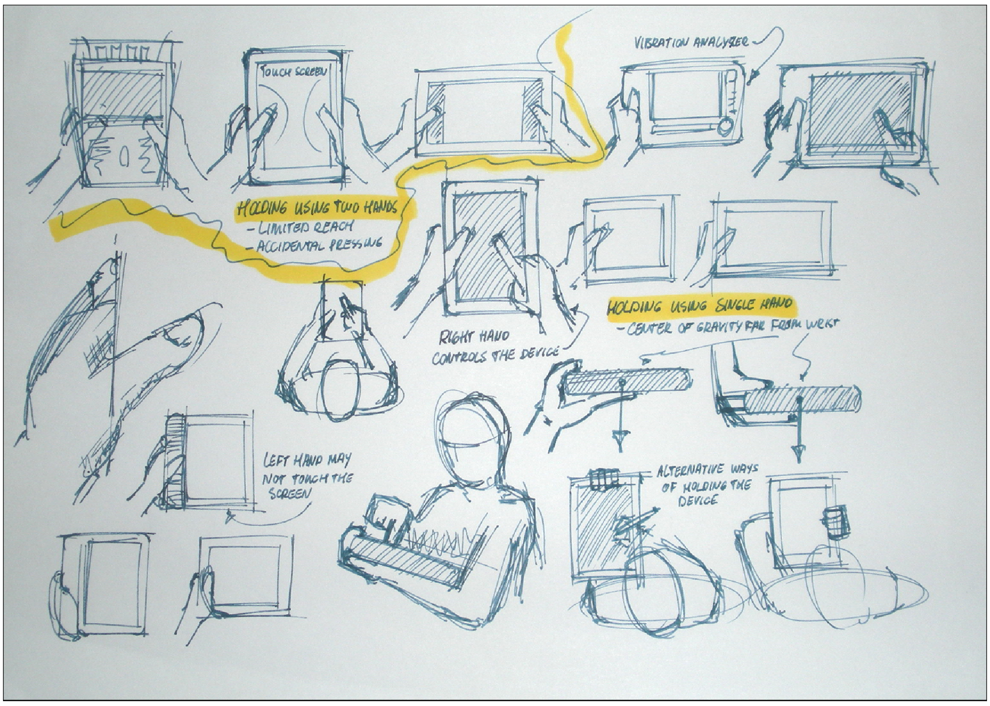
The Almelo division is home to Benchmark's European Development Engineering group, which can execute complex and innovative projects from initial design concept through product manufacturing to order fulfillment. To save costs, it can transfer production to its sister manufacturing facility in Brasov, Romania, which it maintains close relations with. The products it develops may range from small wireless remotes for hearing instruments to large electronics housing units for semiconductor lithography equipment.

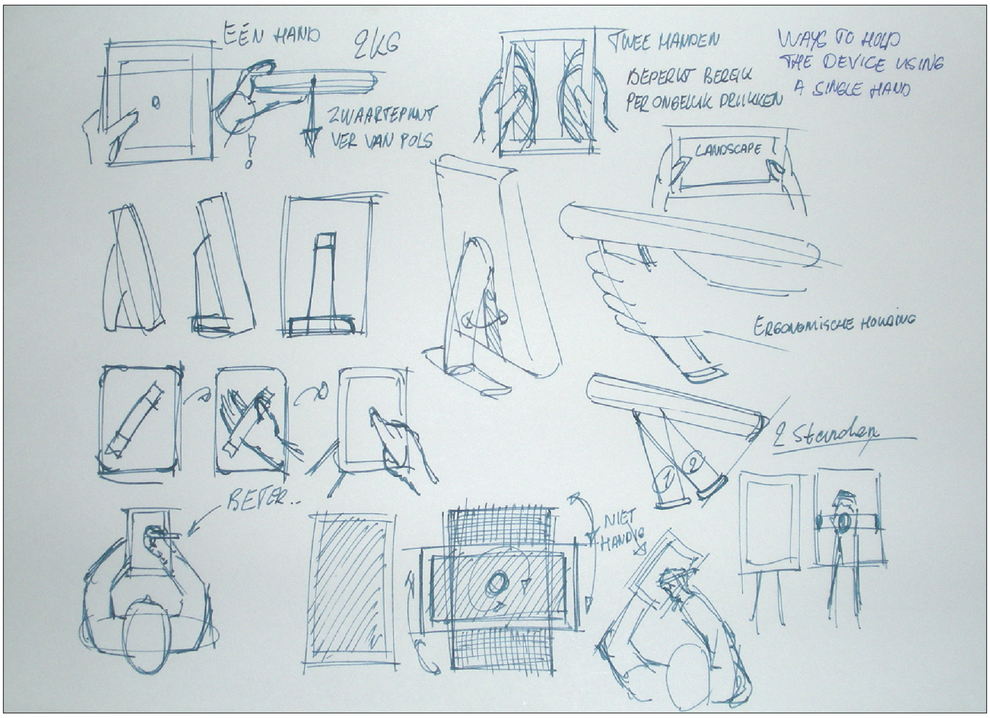
Benchmark's history with the Almelo facility began only in 2007, when the company merged with its then-owner, contract manufacturer Pemstar. The site has its roots with Philips Electronics' Test and Measurement Division. For many years its sole purpose was to develop industrial test and measurement tools, chiefly oscilloscopes. In 1993 Philips sold the site to test tool manufacturer Fluke Corporation, for whom it had been producing portable oscilloscopes. When Pemstar took over in 1999 the Almelo division started to venture into markets outside its traditional field of expertise. The development of test and measurement tools, however, remained a large part of its business.

Appendix B – Ways of Holding The Analyzer



Appendix C – Ideation Sketches





Appendix D – Power Tab Interface Sequence

The next 22 pages show an interface sequence for the Power Factor Analysis function of the Power Tab's Assist mode.

Please, see the accompanying file **Interface_Sequence.pdf**.