XVisor Transformer Expert System

LTC Module, Beta Software

1000510

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Technical Progress, December 2000

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ABSTRACT

Recent surveys indicate that LTC failures account for approximately 20% of transformer failures and nearly 50% of transformer troubles. In addition, diagnostic tools used previously have been ineffective in accurate diagnosis of incipient faults. In recent years, the use of dissolved gas-in-oil analysis and oil quality analysis has gained popularity as a non-invasive means of fault detection and condition assessment. However, the use of these tools requires a great deal of expert knowledge and experience with the particular LTC under consideration. Consolidation of this knowledge in an expert system such as XVisor will enable a greater reliance on these newer techniques for LTC diagnosis as well as greater utilization of other available information. The XVisor software release with the LTC module will be known as XVisor, 1.1

The methodology for implementing LTC diagnosis is exactly the same as that used for components previously implemented in XVisor. Previously implemented knowledge centered mainly on the main components of the transformer itself (i.e. core and coils). The LTC diagnosis implementation simply extends the current knowledge base to include LTC knowledge.

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INTRODUCTION & BACKGROUND

Xvisor1.0 is a rule-based expert system that enables utilities and other users to determine the condition of their transformers and associated components. With the help of XVisor, users are able to assess the condition of a transformer, and determine, with a reasonable degree of confidence, if maintenance or repairs are necessary. XVisor utilizes nameplate data, inspection and test results as well as events, such as trip-outs, and repair information, that feed into a diagnostic program. It also has on-line technical help that defines terms, failure mechanisms, tests, inspections, events, and repairs. The rules contained in the XVisor system are extractions of the vast knowledge and experience of transformer experts. This permits personnel who are non-specialists to draw upon this expertise to guide maintenance decisions on power transformers.

IRIS Corporation implemented the XVisor system under contract to EPRI. In October of 1999, Power Delivery Consultants, Inc., met with IRIS Corporation personnel to take over the maintenance and further development of XVisor. Through the rest of 1999 and the first 6 months of 2000, PDC and its software subcontractor, Ulrich associates Inc., have become familiar with the software, performed certain corrections which were required and participated in the initial stages of developing XVisor 2.0. The interim software release with the LTC module will be known as XVisor, 1.1

2
LTC MODULE

Recent surveys indicate that LTC failures account for approximately 20% of transformer failures and nearly 50% of transformer troubles. In addition, diagnostic tools used previously have been ineffective in accurate diagnosis of incipient faults. In recent years, the use of dissolved gas-in-oil analysis and oil quality analysis has gained popularity as a non-invasive means of fault detection and condition assessment. However, the use of these tools requires a great deal of expert knowledge and experience with the particular LTC under consideration. Consolidation of this knowledge in an expert system such as XVisor will enable a greater reliance on these newer techniques for LTC diagnosis as well as greater utilization of other available information.

The methodology for implementing LTC diagnosis is exactly the same as that used for components previously implemented in XVisor. Previously implemented knowledge centered mainly on the main components of the transformer itself (i.e core and coils). The LTC diagnosis implementation simply extends the current knowledge base to include LTC knowledge.

LTC Technology

A Load Tap Changer (LTC) is a switching device equipped with current-carrying contacts connected to transformer taps used for changing voltage under load, without interruption in power flow. The design of these mechanisms varies from manufacturer to manufacturer and from model to model. All of these designs, however, have some similarities. First, two taps, the previous tap and the next tap, must be connected in some way to prevent interruption in power flow. To limit circulating current in this bridging position, an impedance must be connected between the adjacent taps.

Switching Mechanisms

Mechanisms for diverting the current and selecting tap fall into three broad categories:

- Diverter (arcing) switch type
- Vacuum-interrupter type
- Selector switch type

Selector Switch Type

The selector switch type is the simplest type of switching mechanism. This type of mechanism combines the duties of selecting tap position and interrupting current. In its simplest form, the selector switch consists of a set of stationary contacts, with one for each tap position, and two moving contacts. Connected in series with each moving contact is a transition impedance to limit circulating current while the contacts are bridging two taps. To change tap, one of the moving contacts is simply moved rapidly to the next tap. To complete the tap change, the second moving contact is then brought over to the next tap, so that both moving contacts are on the same stationary tap.

In more complicated selector switch arrangements, transition contacts are used in addition to the main moving contacts. In this type of arrangement, the transition contacts make before the main contact. The following is a typical sequence for changing tap using this configuration:

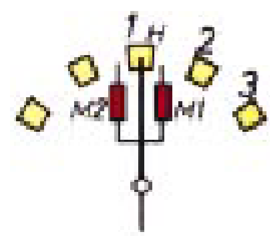

Figure 2-1
Selector Switch Operating Position

Prior to the tap change operation, the main contact (H) is connected to one of the stationary contacts. The transition contacts (M1 and M2) are not connected to any of the stationary contacts and are resting in the space between stationary contacts.

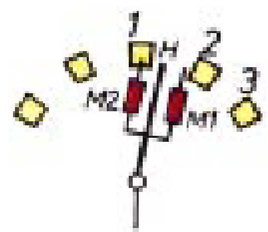

Figure 2-2
Selector Switch Tap Change Operation – Part I

At the start of the tap change operation, the first transition contacts (M2) makes with the stationary contact of the current tap position. Once contact is made between the first transition contact and the stationary contact, the main contact moves off of the stationary contact.

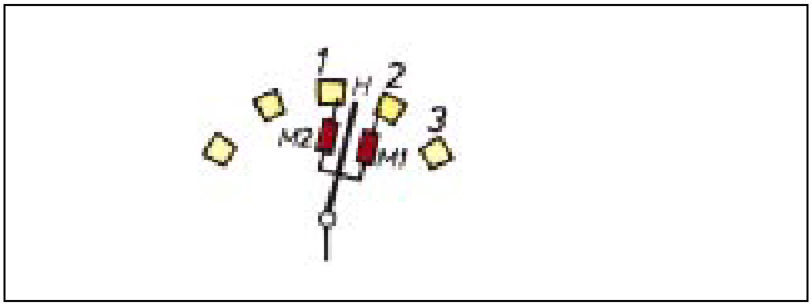

Figure 2-3
Selector Switch Tap Change Operation – Part II

Next, the second transition contact (M1) makes with the stationary contact of the next tap position. This is called the bridging position, since the tap changer is now bridging two taps. Note the two transition impedances are now limiting the circulating current.

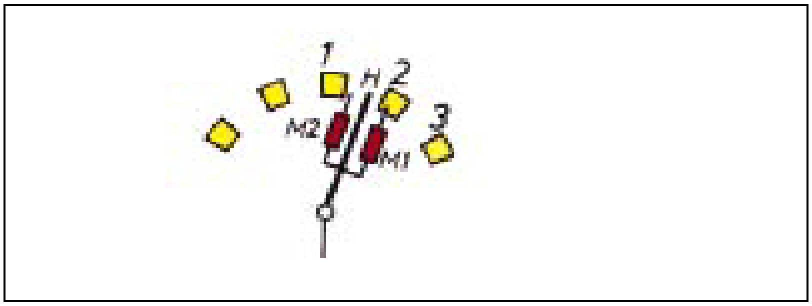

Figure 2-4
Selector Switch Tap Change Operation – Part III

As the tap change operation proceeds, the second transition contact moves further on to the next stationary contact, while the first transition contact moves off of the previous stationary contact.

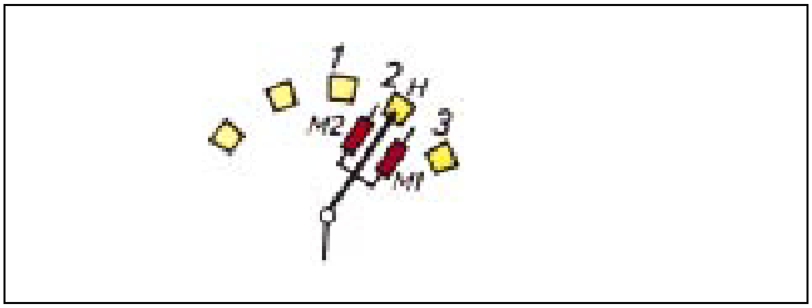

Figure 2-5
Selector Switch Tap Change Operation Complete

Finally, the main contact makes with the next stationary contact and the second transition contact moves off of this stationary contact so that the load tap changer is now in the original configuration, but on the next tap position.

Diverter Switch Type

This type of switching mechanism separates the duties of tap selection and current interruption into two separate devices. The tap selector is similar to the selector switch described above, however, it does not interrupt current. The tap selector generally consists of several stationary contacts and a set of moving contacts. To select the tap position, the moving contacts are simply moved from one stationary contact to the next.

Current interruption is accomplished by a set of arcing contacts. These contacts are usually made of a material with high ablation resistance, such as a tungsten/copper alloy.

The following set of diagrams is an explanation of the tap change sequence of an LTC employing a diverter switch mechanism. This LTC consists of two moving tap selector contacts, several stationary tap selector contacts, and two diverter switches. Note that the heavy lines indicate the path of load current and the arrows show the path of the circulating current.

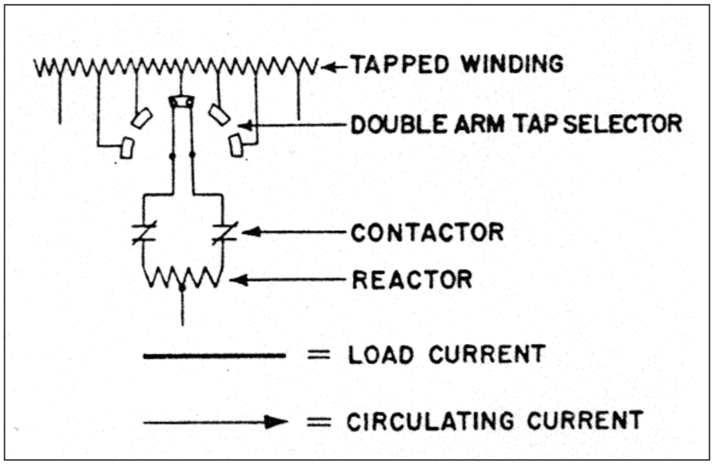

Figure 2-6
Typical Configuration of Diverter Switch Type LTC

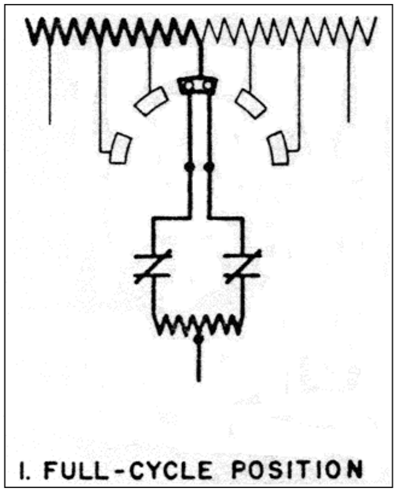

Figure 2-7
Diverter Switch Type Operating Position

The operating position for this LTC is with both movable tap selector contacts on the same stationary tap selector contact, which is connected to the current tap. Note that both diverter switches are closed. This is known as the full-cycle position.

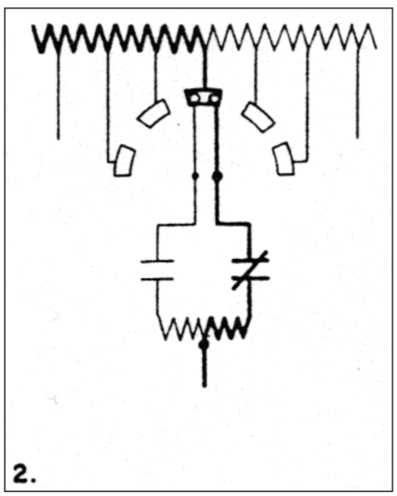

Figure 2-8
Diverter Switch Type Tap Change Operation – Part I

At the start of the tap change operation, one of the diverter switches is opened, forcing full load current to flow in the other branch of the circuit.

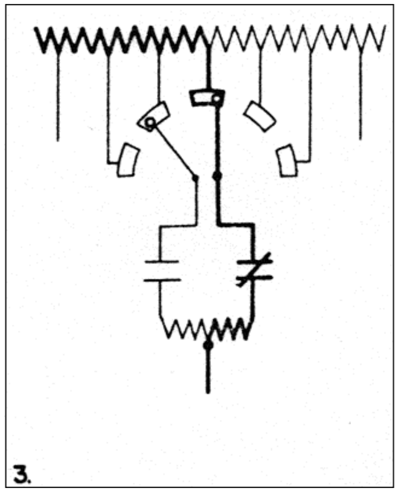

Figure 2-9
Diverter Switch Type Tap Change Operation – Part II

The movable tap selector contact that is connected to the opened diverter switch is then moved to the next tap position. This is safely done since there is no current flowing in this branch of the circuit.

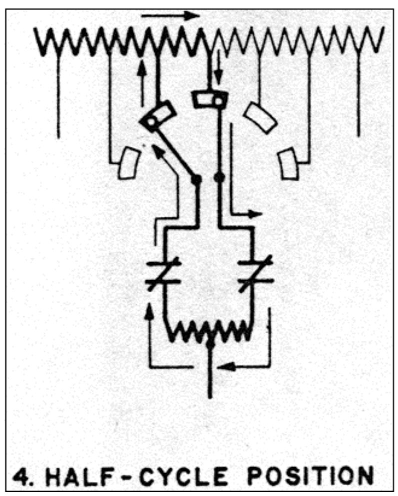

Figure 2-10
Diverter Switch Type Tap Change Operation – Part III

The opened diverter switch is then closed, allowing current to again flow in this branch of the circuit. Since there is a voltage difference between the two taps now connected to the circuit, a circulating current will flow, designated by the arrows. This current is limited by the transition impedance. This is called the half-cycle position. This is sometimes used as an operating position in reactance-type LTCs when more voltage steps are required. Use of the half-cycle position as an operating position effectively doubles the number of voltage steps. The voltage in the half cycle position is the average of the voltage at each of the two connected tap positions.

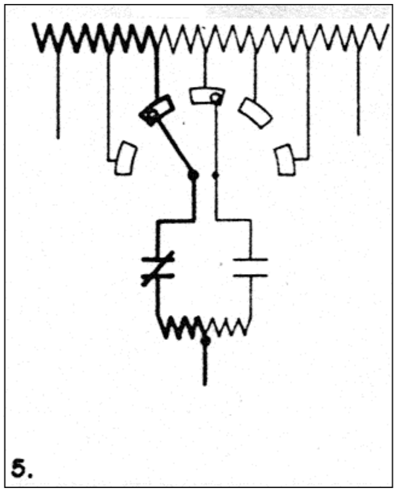

Figure 2-11
Diverter Switch Type Tap Change Operation – Part IV

Continuing the tap change operation, the diverter switch connected to the previous tap position is now opened. This is the diverter switch that remained closed in the previous half-cycle of the tap change operation. This interrupts current flow in the second branch of the circuit.

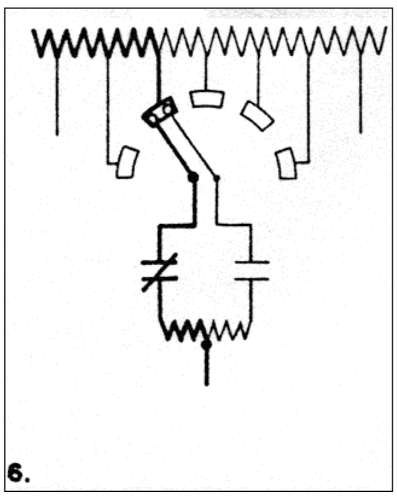

Figure 2-12
Diverter Switch Type Tap Change Operation – Part V

The second moveable contact of the tap selector is then safely brought from the previous tap position to the next tap position, such that both moveable contacts of the tap selector are now resting on the same stationary contact.

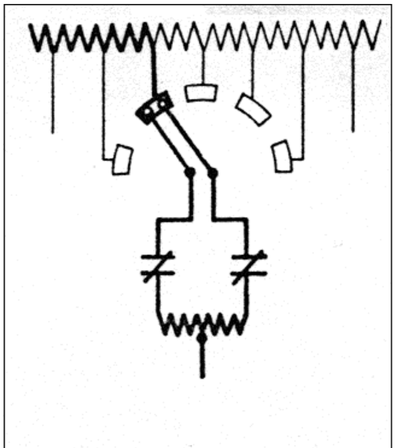

Figure 2-13
Diverter Switch Type Tap Change Operation Complete

The second diverter switch is then closed to complete the circuit and allow current to flow in the second branch of the circuit. The LTC is now in the same configuration as it was prior to the tap change operation, however the next tap is selected.

Vacuum Interrupter Type

Electrically, the vacuum interrupter type of switch mechanism is the same as the diverter switch type. The difference lies in the mechanics of the diverter switch operation. In the diverter switch type outlined above, the arcing due to the opening and closing of the diverter switch occurs in the oil. In the vacuum interrupter type, a vacuum interrupter is used for the diverter switch operation. The vacuum interrupter is a set of contacts sealed in a vacuum chamber. Usually, one of the contacts is stationary, while the other is a spring-loaded moveable contact. The vacuum serves to limit the arc duration and intensity, thereby limiting the damage and erosion of the contacts. A typical vacuum interrupter is shown in Figure 2-14.

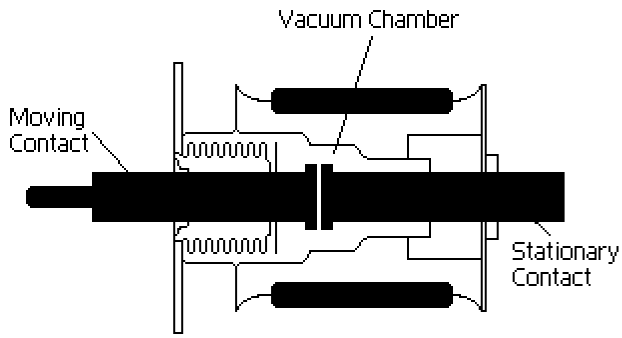

Figure 2-14
Diagram of Typical Vacuum Interrupter Assembly

Transition Impedance

There are two types of transition impedances used in LTCs, resistance and reactance. Resistance-type LTCs are characterized by short switching durations, in order to limit resistor heating. Since the transition resistance undergoes heating during the tap change operation, the transition resistance is susceptible to coking.

Reactance-type LTCs feature a center-tapped reactor, generally known as a preventive autotransformer. This preventive autotransformer is capable of carrying full load current continuously. Therefore, LTCs of this type are capable of operating on the bridging, or half-cycle, tap positions, effectively doubling the number of voltage steps for a given number of physical taps. In addition, since this reactance does not endure significant heating during tap change operation, the rapidity with which the tap change must be completed is less than with resistance-type LTCs. Therefore, reactance-type LTCs can use slower, less complicated, and consequently more reliable, drive mechanisms.

Change-over Selectors and Tap Winding Configuration

The number of available tap positions may effectively be doubled by employing a change-over selector. A change-over selector is a switch used to reconfigure the tap winding when the LTC has reached the limit of available tap positions. There are two ways to reconfigure the tap winding, and thus two types of change-over selectors. The first type of change-over selector is called the reversing switch. In this configuration, the reversing switch connects the tap winding in either a buck (lower) or boost (higher) configuration as the tap selector passes through neutral. This configuration is shown in Figure 2-15 Item ii.

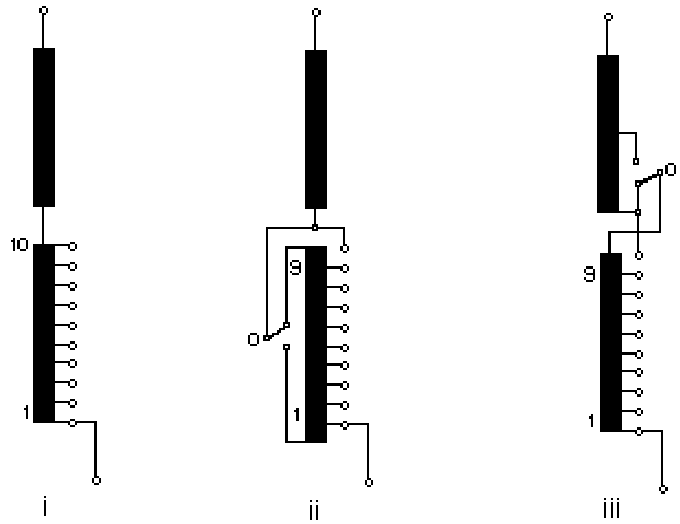

Figure 2-15
Tap Winding Configuration for Use With or Without a Change-Over Selector

The second type of change-over selector is a course change-over selector. This type of change-over selector simply switches a portion of the winding, called a course winding, in or out as the tap changer operates through neutral. This configuration is shown in Figure 2-15 Item iii.

The mechanical operation of the change-over selector is tied to the drive mechanism of the tap selectors and diverter switches. The change-over selector only operates as the LTC passes through neutral. Since some LTCs may operate only in certain sections a majority of the time, it is possible that the changeover selector is rarely exercised. This makes the reversing switch especially prone to failure or degradation from coking.

LTC Compartments & Physical Layout

There are two general types of LTCs with regard to installation location, in-tank and separate compartment. As their names suggest, the in-tank type LTCs are located inside the transformer main tank. These tap changers usually consist of a tap head, which is mounted to the cover of the main tank, with the diverter switch (if applicable) and tap selector mounted below.

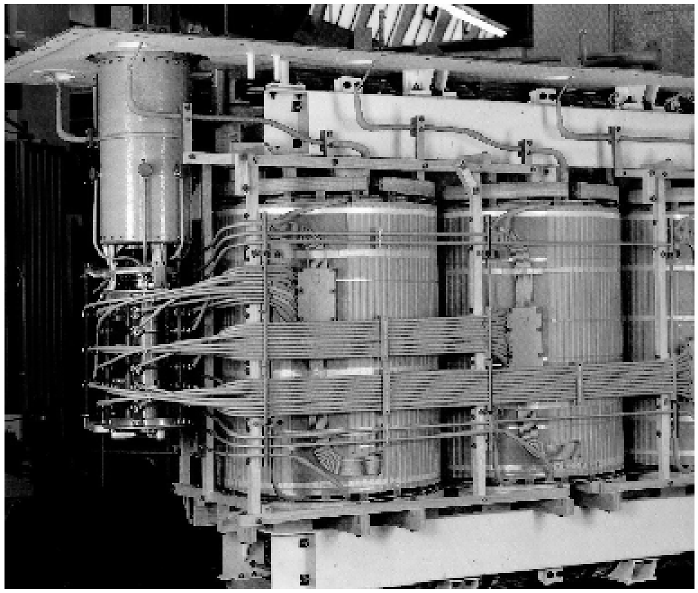

Figure 2-16
In-Tank LTC Mounted to Tank Cover

The separate compartment type of LTC consists of one or two compartments welded or bolted to the outside of the main tank. Tap leads are passed into the main compartment through an oil-tight tap board. This is to prevent any LTC compartment oil with degradation products due to arcing from entering the transformer main tank.

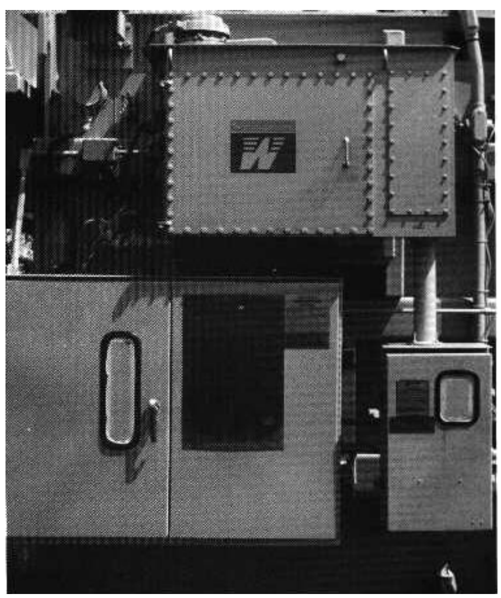

Figure 2-17
Separate Compartment Type LTC Mounted on Main Tank

Tap changer mechanisms may be divided and mounted in separate compartments. Generally, this will only be seen in LTCs with a Diverter Switch mechanism. Occasionally, LTCs of this type may be divided into two separate oil-tight compartments to prevent the oil degradation products, resulting from the arcing at the diverter switch contacts, from contaminating the oil of the tap selector and contributing to the deterioration of the tap selector contacts.

Breather Type

The LTC compartment is either a sealed tank, or a tank open to the atmosphere through some type of breather or conservator. Those open to the atmosphere are classified are free-breathers or desiccant breathers. A free-breathing LTC compartment is one in which the air space above the oil level in the compartment is free to exchange with the outside atmosphere. A desiccant breathing LTC compartment is similar to a free-breathing compartment, except that a dehydrating breather unit is used to remove moisture from the incoming air to prevent the acceleration of oil degradation due to the presence of moisture.

Note that oil expands as the temperature increases. For sealed compartments, this means that the pressure inside the compartment will increase with an increase in temperature. Sealed compartments are usually equipped with a pressure-relief device designed to open at a specified pressure. This is usually a one-way valve, resulting in a vacuum upon cooling. Free-breathing units will generally have an internal pressure equal to atmospheric pressure, while desiccant breathers generally have an internal air pressure slightly higher than atmospheric pressure.

Drive Mechanisms

LTC operation is generally driven by the operation of an electric drive motor. This motor may either be connected directly to the LTC switching mechanisms or indirectly through a charged spring. In the cases of an indirect connection through a charged spring, the drive motor is used to charge the spring prior to the actual tap change operation. This type of drive mechanism is used when it is desirable to limit the duration of the tap change operation. A direct drive is usually used in all other cases.

History and Tests

The diagnosis of an LTC component is based upon historical data from tests and repairs as well as description information such as manufacturer and model. In past practice, little or no diagnostic testing was done to assess the operating condition of an LTC. Rather, time-based maintenance schemes were employed. The trend is now toward condition-based maintenance and diagnostic testing. XVisor is well suited for this type of analysis, and has been programmed with a great deal of expert knowledge and state-of-the-art diagnostics.

The LTC diagnostics in XVisor are integral with the existing transformer diagnostics. Therefore, data entry and diagnosis are exactly the same as for other components in XVisor. As with other components, the LTC component is first added to the transformer component. Certain descriptive facts are obtained up front. These descriptive facts include manufacturer, model number, breather type, filter operation and number of tap positions.

Following the addition of the LTC components, historical facts are then added. There are several different activities that result in historical data. These activities include Repairs, Replacement, Tests, and Operating Data. Some of this information may or may not be routinely obtained. Certain diagnostic practices, such as dissolved gas analysis, are just now being accepted as a viable indicator of LTC condition.

The historical activities available in XVisor are summarized in the following:

Repairs and Replacements

- Replace Various Contacts (Original or Upgraded)
- Replace Tap Board and/or Gaskets

Tests

- Temperature Differential
- Oil Physicals
- Dissolved Gas Analysis
- Operations Counter Reading
- Tap Position (Current and Last)
- Oil Level
- Steady-state Motor Current
- Motor Index
- Time to Complete Tap Change

Failure Mechanisms

- Coking of Reversing Switch
- Localized Overheating – Inadequate Contact Mating
- Excessive Wear – Inadequate Contact Mating

- Vacuum Bottle Improper Operation
- Localized Oil Overheating
- Oil Contamination
- Erratic LTC Operation – Defective Mechanical Components
- Erratic LTC Operation – Defective Control System Components
- Deterioration of Gaskets and Seals
- Coking of Leads or Cables
- Transition Resistance Overheating

3
XVISOR SOFTWARE OPERATION

Adding a Load Tap Changer

To add a load tap changer, click on the transformer that you wish to define it for. ***NOTE:*** *You cannot define a load tap changer without first defining a transformer.* Once the appropriate transformer is highlighted, click on the Add button. You will see a drop down list with six choices (depending on whether or not any of the six choices have already been defined), "Windings", "Oil", "Load Tap Changer", "De-energized Tap Changer", "Core" & "Tank and Associated Components". Select the "Load Tap Changer" menu item. You will be brought to the following dialog box.

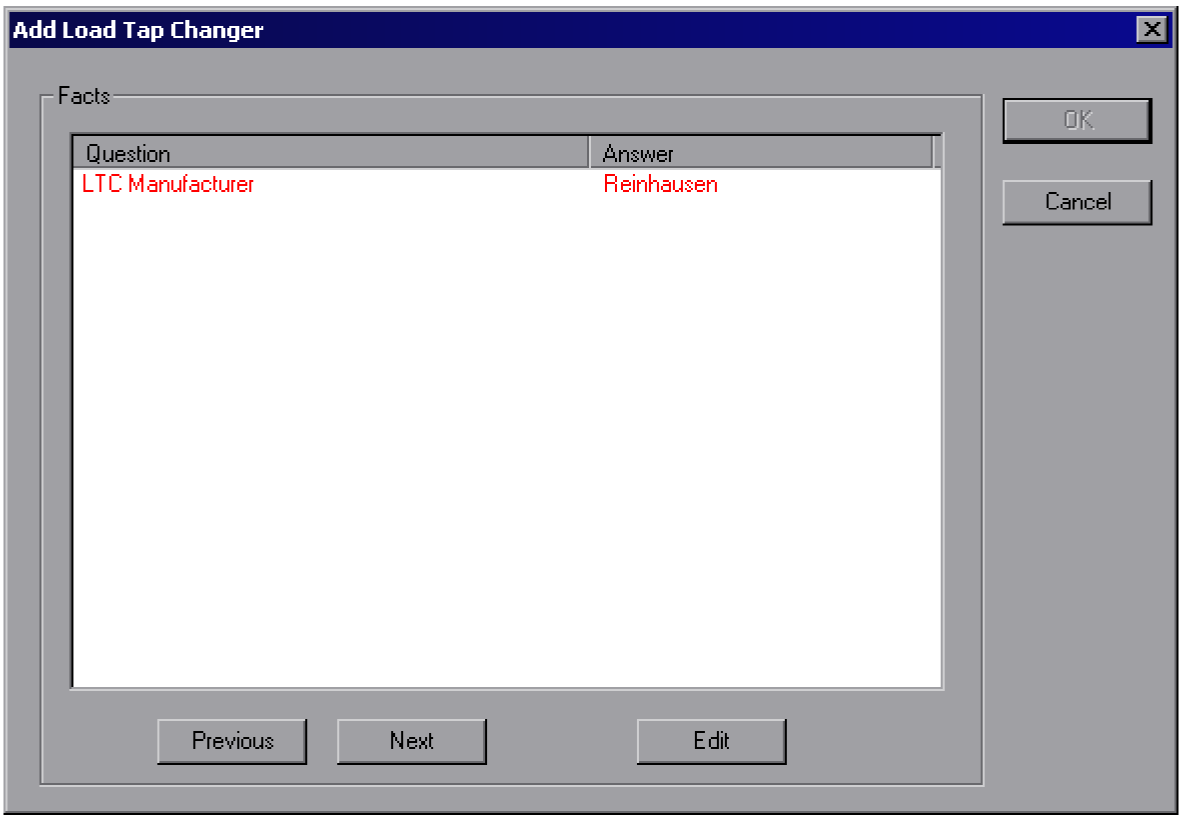

Figure 3-1
Add Load Tap Changer Dialog Box

Complete (edit) the information as necessary and then click OK.

Name the new load tap changer with a unique name. This will make reports easier to analyze.

Adding a History Record to a Load Tap Changer

There are four types of history records that can be added to a load tap changer. We will outline the various choices available in each type in the following two sections.

Test

To add a test to a load tap changer, select the load tap changer and click the Add button. A menu will pop up. From that menu select “Test”, a further sub-menu will pop up with the following choices:

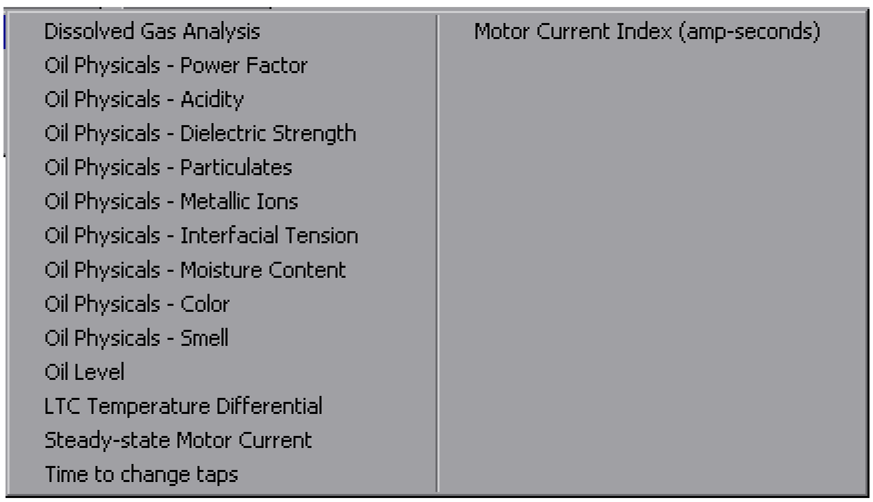

Figure 3-2
Load Tap Changer Test Sub-Menu

Select the appropriate test. You will see a dialog box similar to the following:

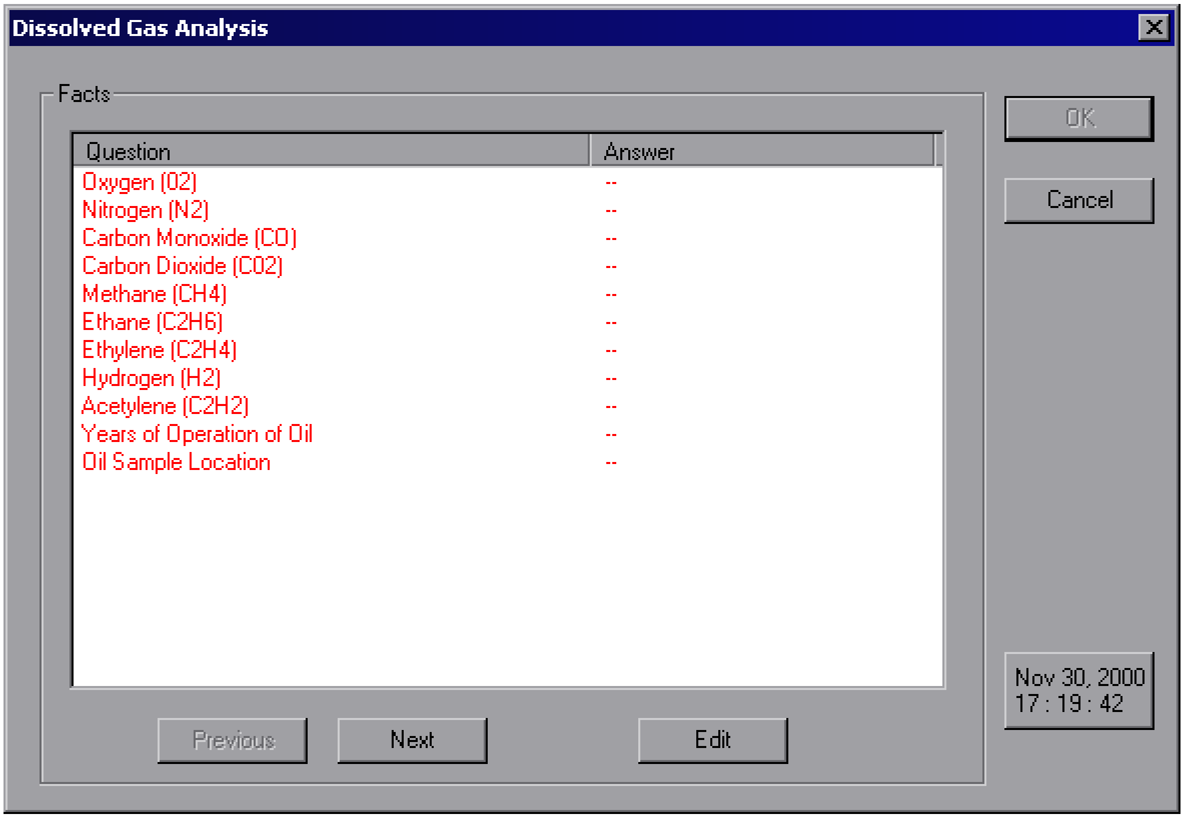

Figure 3-3
Typical LTC Test Dialog Box

Fill out the information as thoroughly as possible and click OK. The process is identical for all test types.

NOTE: *If you wish to change the date see Section 4.3.1. of the XVisor 1.0 Instruction Manual.*

Repair

To add a repair to a load tap changer, select the component and click the Add button. A menu will pop up. From that menu select "Repair", a further sub-menu will pop up with the following choice:

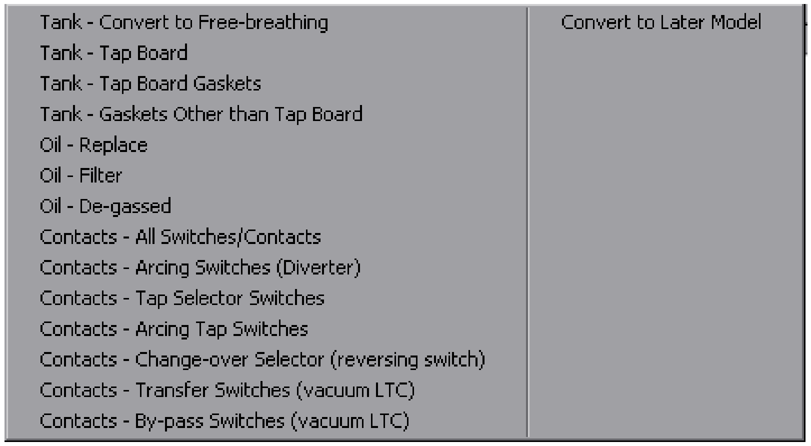

Figure 3-4
LTC Repair Sub-Menu

Select the appropriate test. You will see a dialog box similar to the following:

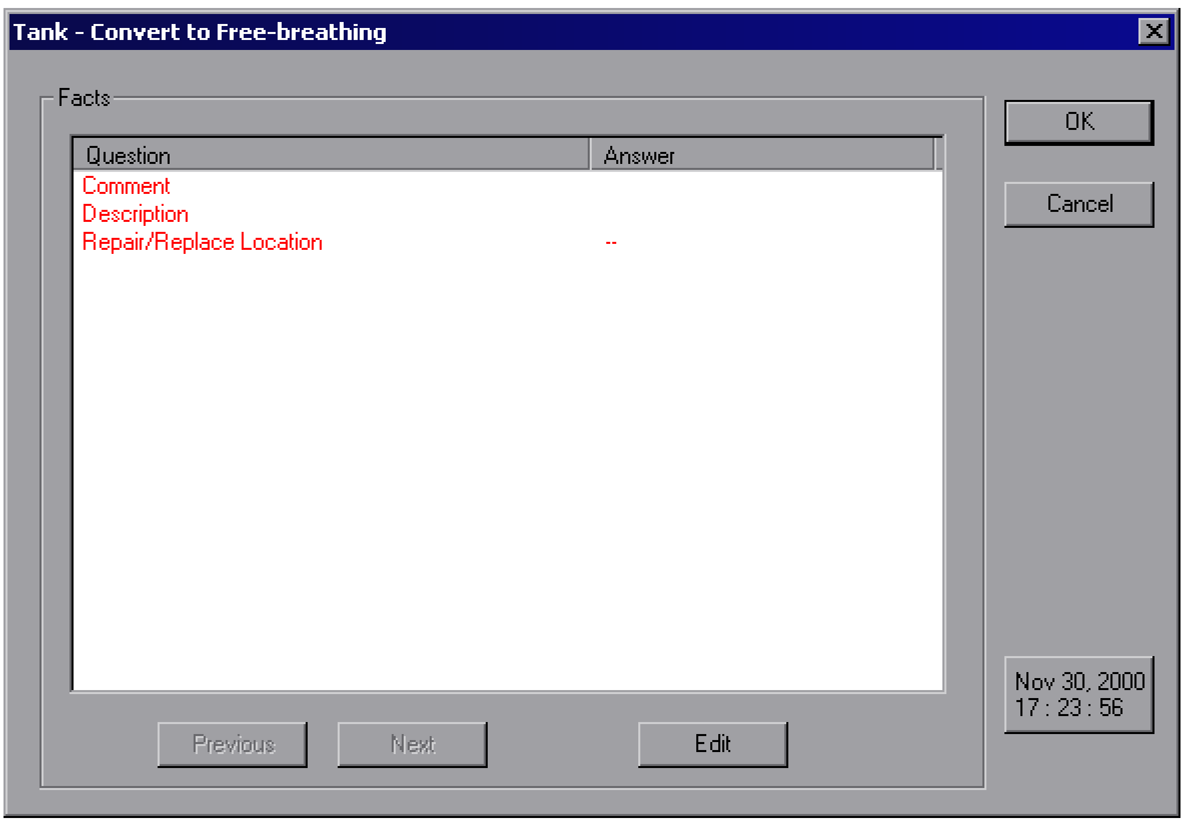

Figure 3-5
Typical LTC Repair Dialog Box

Click OK to report the repair.

NOTE*: If you wish to change the date see Section 4.3.1. of the XVisor 1.0 Instruction Manual.*

Note

Adding a note to a load tap changer is the same as adding a note for any other equipment component. See Section 4.3 for details on adding a note.

Operating Data

To add operating data to a load tap changer, select the load tap changer and click the Add button. A menu will pop up. From that menu select "Operating Data", a further sub-menu will pop up with the following choices:

Figure 3-6
Load Tap Changer Operating Data Sub-Menu

Select the appropriate operating data. You will see a dialog box similar to the following:

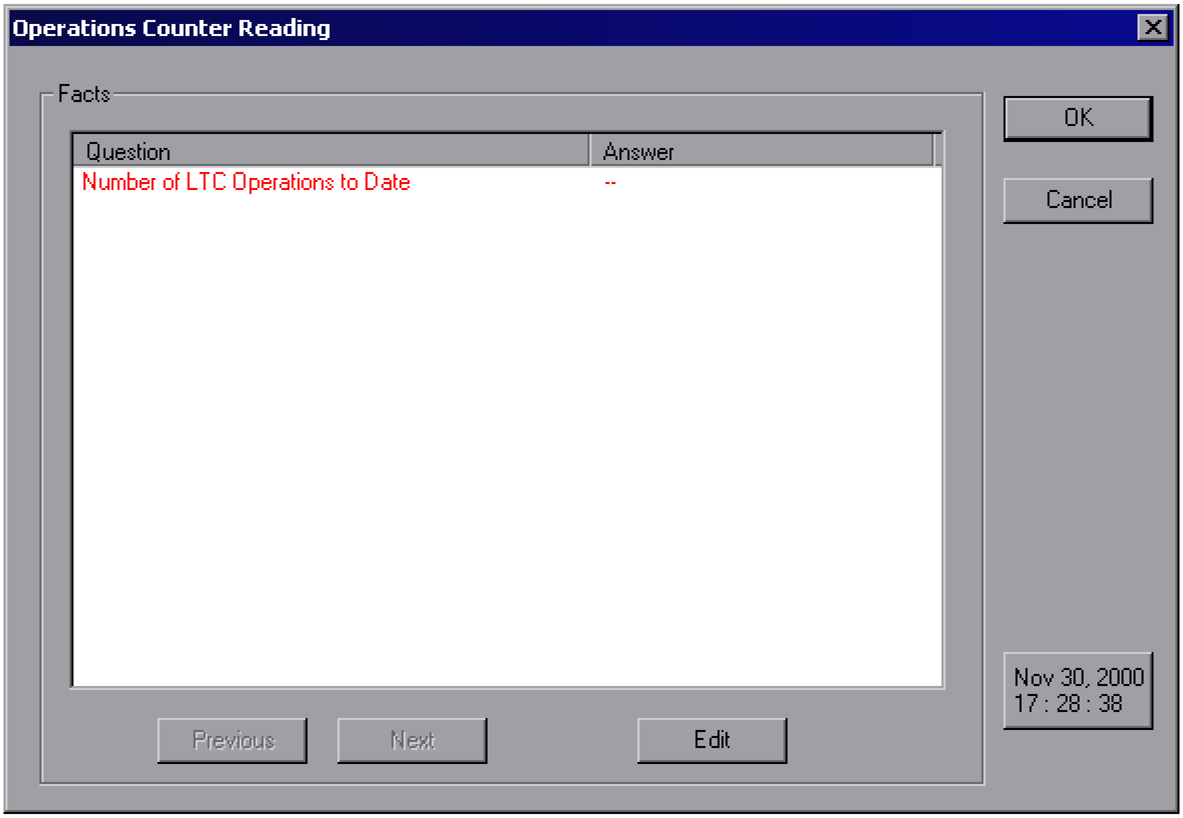

Figure 3-7
Typical LTC Operating Data Dialog Box

Fill out the information as thoroughly as possible and click OK. The process is identical for all operating data types.

***NOTE**: If you wish to change the date see Section 4.3.1. of the XVisor 1.0 Instruction Manual.*

4
SOFTWARE DEVELOPMENT EFFORTS

During the performance period, eight areas of activity were undertaken with respect to XVisor software changes. These are discussed in the following sections.

Action Item Database

A database for action items (bugs, problems, and suggested enhancements) was created using Lotus Approach. The entries are stored in Dbase III format, and so can be viewed using most modern database tools and spreadsheets.

There are 30 entries total. The following gives a summary of the items. Some of the items listed as “Open” are scheduled to be completed within the very near future.

Table 4-1
Summary of Action Items

Category	# Closed	# Open	Total
Database error	1	2	3
Installation problems	2	0	2
Software errors (bugs)	10	6	16
Desired enhancements	1	7	8
Documentation and Help System	1	1	1
TOTAL	15	16	31

Code Clean-up

The first step in creating XVisor 1.1, was to upgrade the code to all of the newest development tools: Visual C++ 6.0 (versus 4.2), Crystal Reports 8.0 (versus 5.0), and Access 2000 (versus Access 95).   As part of this effort, we did a lot of general cleanup in terms of removing large blocks of unused code (including entire files) and fixing potential errors identified by an automated code-checking program (PC-Lint 7.0).

A good example of this work involves the “Boolean” (true/false) variable type. Version 1.0 of XVisor employed three types of Booleans:

- bool (the intrinsic C++ type that has values true and false),
- BOOL (an integer value that by convention uses 1 for true and 0 for false),
- BOOL_TYPE (an integer coding scheme with three values: 0 for false, 1 for true, and 2 for unknown).

Unfortunately, there were many places where BOOL and BOOL_TYPE were getting mixed up. To the best of our knowledge, we have fixed all such discrepancies.

In addition, we worked on fixing the highest-priority bugs that had been reported.

Crystal Reports

Crystal Reports (CR) is a popular third-party application provided by Seagate Software; it enables programs (and users) to create sophisticated custom reports given an ODBC-compliant database. Unfortunately, its very popularity created a deployment problem: if a user has programs with other versions of CR, there would ensue conflicts in system DLLs.

We spent a considerable amount of time upgrading to the newest version of Crystal Reports, in order to resolve the DLL conflicts and make installation easier. Unfortunately, not all of the old reports could be converted (Seagate Software was never able to determine why), and not all of the conflicts were resolved. Therefore, a decision was reached to remove CR entirely from the program and to replace the reports with custom software in a future revision. Therefore, Version 1.1 of XVisor does not have the report generation capabilities offered by Version 1.0.

Inclusion Rules for Failure Mechanisms

One of the more significant bugs was that the Inclusion Rules for failure mechanisms weren't working. It turned out that this "feature" had never been implemented in XVisor 1.0. Even though incorporation of this new feature was not included within the SOW, it has been implemented for Version 1.1. The reason is that the LTC logic is heavily dependent on this "missing feature."

External Interface (COM)

Significant effort was invested in making XVisor callable from external programs. It is now possible to call XVisor from other programs, or from applications such as Microsoft Word or Excel. When called externally the XVisor GUI is bypassed, and things that a user would normally do through the GUI are done through subroutine calls. For example, a file may be loaded, a test added to a particular component, and the diagnosis recomputed, all under command from an external program. The external program may then, of course, access the risk-of-failure values.

Component Object Model (COM) technology was added to XVisor to provide the external interface. Most operating systems allow one program to call another. COM takes this a step further, and lets one program call individual subroutines and access internal data items in a second program. By adding COM to XVisor we made it possible to integrate XVisor with other programs – notably MMW.

The COM calls added to XVisor provide the following capabilities:

- Loading a file, or getting the name of the currently loaded file.
- Stepping through the component tree.
- Setting or getting the "Question / Answer" pairs that define a test. For example, for a Dissolved Gas Analysis, one question is "CO2", and the answer would be the carbon dioxide concentration in the transformer oil, in parts-per-million. Once all the question/answer pairs have been defined, the test may be added to a component's history.
- Performing a diagnosis.
- Accessing the risk-of-failure values.

The question/answer pairs are very generic – any question and any answer may be specified. This allows the external interface to be very flexible: if new test types or new component types are added to XVisor, no modifications to the external interface will be required.

An example Microsoft Excel spreadsheet was created to illustrate the COM features that were added to XVisor. From the spreadsheet, a single pushbutton invokes XVisor, adds a test, and performs a diagnosis, then displays the resulting risk-of-failure values. This spreadsheet was used partly as a debugging tool -- a simple way to call the different COM functions as we added them. It also served as an example, showing the different steps required to access XVisor through COM.

New Installation Program

A new InstallShield program has been prepared to install the beta version of XVisor 1.1.

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