Experiences with a PC-Based Short Circuit and Relay Coordination Program

Jay Campbell
Sierra Pacific Power Company
P.O. Box 10100
Reno, Nevada 89502

Sherman Chan
Advanced Systems for Power Engineering
P.O. Box 60849
Palo Alto, California 94306

INTRODUCTION

Sierra Pacific Power Company (SPPCo) is an investor-owned utility serving approximately 250,000 customers in northern Nevada — a service territory of some 50,000 square miles.

SPPCo was a user of the *Philadelphia Electric Network Fault Analysis Program* on an IBM mainframe until 1986, when the program was replaced by the *ASPEN Short Circuit Program™*. The *ASPEN Short Circuit Program* was a significant improvement over the *Philadelphia Electric Network Fault Analysis Program* both in speed and fault capabilities, but it lacked interactivity and graphical capabilities. In mid-1988, SPPCo acquired a PC-based, interactive short circuit/relay coordination program called *ASPEN OneLiner™* to supplement the mainframe short circuit program for relay coordination. This paper describes SPPCo's experiences with *ASPEN OneLiner*.

INSTALLATION

The *OneLiner* program runs on a PC at SPPCo with the following components:

Hardware

- An AST Research PC with a 20-MHz 80386 CPU
- An 80387 math coprocessor
- 2 Mbytes of RAM (above the 1 Mbyte standard memory)
- A 40 Mbyte internal fixed disk
- A Microsoft Mouse

Software

- MS DOS operating system
- Microsoft Windows/386™
- Additional report writing and computer maintenance software

Peripherals

- An HP-7475A plotter
- A color monitor with an Enhanced Graphics Adapter (EGA) card
- A 132-column dot-matrix printer

Presented Before the 16th Annual Western Protective Relay Conference, Spokane, WA   October, 1989

Of the 2 Mbytes of extra RAM, only 1 Mbytes above the standard memory is required to run *OneLiner* under Windows/386. The extra memory allows for a disk cache and a RAM disk, both of which contribute to a faster execution time.

ASPEN provided two days of training at SPPCo when the program was first installed. The training consisted of one day of formal classroom instructions and one day of hands-on sessions. The program proved to be very easy to learn and to use. Most users at SPPCo mastered the program in one to two days. New users who have not received formal training can learn the program from a written tutorial that is included in the user's manual.

The very first step in using *OneLiner* was to create a Base Case File that contains both the short-circuit data and the graphical information of the one-line diagram. This was done by "importing" a Network Data File that contained the short circuit data in text form.

The Network Data File for the SPPCo system was converted from an old Philadelphia Electric Company short-circuit data file using a conversion program provided by ASPEN. The conversion was automatic, except that the user had to type in the nominal voltages which were missing in the Philadelphia Electric Company format. See Figure 1 for an illustration of the initial data-preparation tasks.

When importing the Network Data File, the user specifies the location of the busses, one by one, by clicking the mouse button on the screen. *OneLiner* automatically adds the generator, load and shunt on the bus, as well as branches connecting the bus to its neighbors. This process of creating the one-line diagram for the SPPCo system took two weeks, but it had to be done only once.

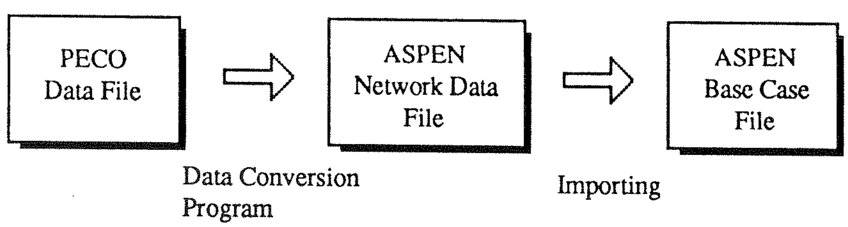

Figure 1: Initial data preparation for *OneLiner* consists of two steps: (1) Converting a Philadelphia Electric Company data file to an ASPEN Network Data File, and (2) Importing the resulting Network Data File to create an ASPEN Base Case File.

OneLiner came with a database of overcurrent relay characteristics in a Relay Library. The Relay Library is user-maintained. Each user can add, delete or modify the relay characteristics using an auxiliary program called the *ASPEN RelayEditor*. SPPCo, being the very first user of *OneLiner*, had to create a number of relay characteristics from scratch. The process of defining thirty characteristic families took three days. (Later users are spared from this work, since the Relay Library is shared among all users.)

The input data for each new relay type consist of only eight data values: four points on the topmost time lever (usually 10 or 11), and four points on the bottommost time lever (usually 1/2). The user can move the points anywhere on the screen with the mouse. The shape of the curve is updated "on the fly" when the mouse button is released.

PROGRAM BASICS

OneLiner has models for shunts, loads, generators, mutual couplings, lines, phase shifters and a wide variety of 2- and 3-winding transformers. Transformer modeling in *OneLiner* is based on a phase-oriented approach that originated from the Electromagnetic Transients Program (EMTP). This method allows the program to represent exactly auto-transformers with neutral impedances and transformers with complicated neutral connections. The program also has models for overcurrent relays, fuses and distance relays.

The short-circuit data for SPPCo models a distribution and transmission network ranging from 4 kV to 345 kV. The six utilities connected with SPPCo are modeled at the boundary by their network equivalents. All told, the Base Case File for the SPPCo system has about 700 busses, 260 transformers, 370 lines, 3 phase shifters, 69 generators (including source equivalents) and more than 1000 protective relays. All the network and relay data, and graphical information fit into a file of only 90 Kbytes in size. Of the protective devices, SPPCo models nearly 80 different types of overcurrent-relay and fuse characteristics. The Relay Library with these fuse and relay characteristics occupies only 14 Kbytes of memory.

The size of the SPPCo system is close to the limit of *OneLiner,* which can handle up to about 800 busses under the current version of Microsoft Windows. Microsoft Corporation intends to release a new version of Windows in the fourth quarter of 1989 that will allow a virtual machine size of 16 Mbytes, up from the current limit of 640 Kbytes. *OneLiner* will then be able to model a system as large as the WSCC with ease.

OneLiner uses "interactive graphics", a new approach that allows the user to manipulate objects and issue commands by interacting directly with the graphical display of the one-line diagram.

The one-line diagram is always displayed on a pop-up window. Additional information, such as system impedances, voltages, currents and relay operating times, can also be shown on the one-line diagram. Revising the one-line diagram is child's play. With the mouse, point-and-drag editing can move any element. Double-clicking the mouse can bring up any network parameters for review or editing. More on this later.

Full graphics zoom and pan (also called scroll) features are available. With the four zoom factors — 100%, 50%, 10%, and 5% normal size — the user can view the one-line diagram under a wide range of magnifications. See Figure 2. The pan feature makes moving around the one-line a breeze. A "Find Bus" feature, which locates a bus given its name, is handy when one is totally lost.

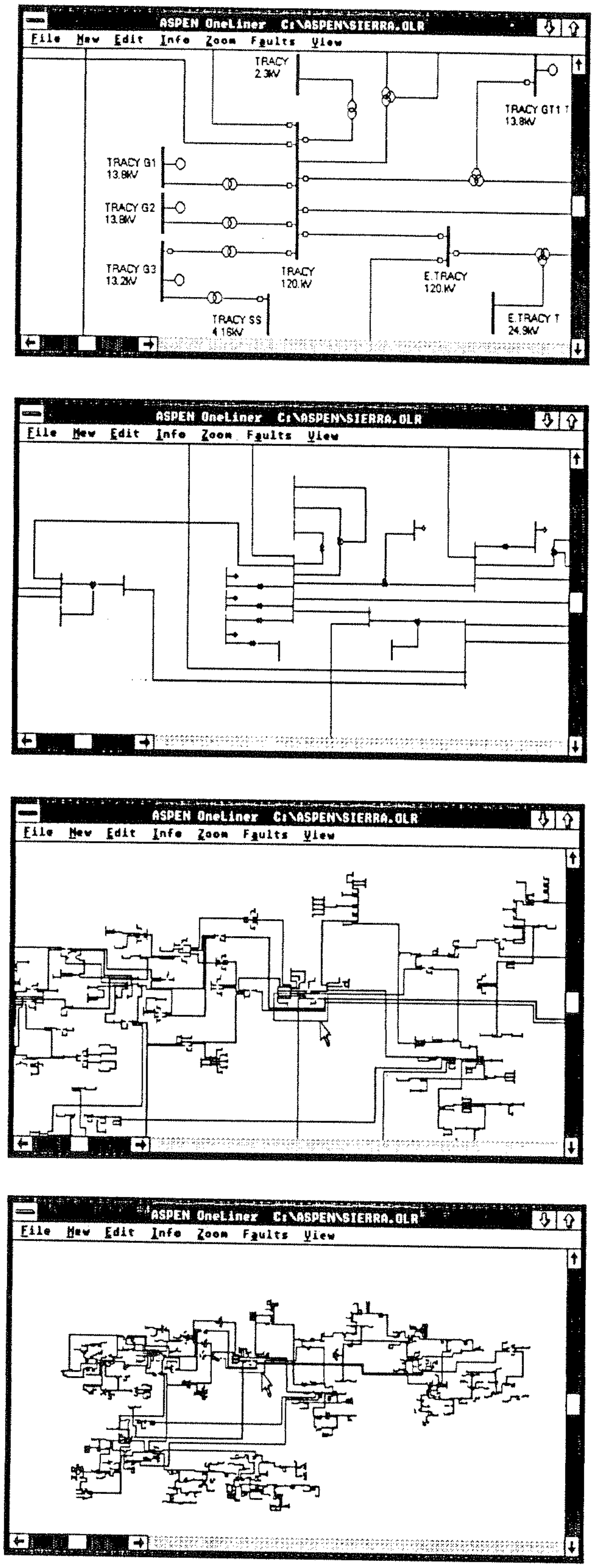

Figure 2: The one-line diagram can be shown in four different magnifications: 1.00x, 0.50x, 0.10x and 0.05x. The entire SPPCo system is visible under 0.05x.

OneLiner can simulate all the classical fault types including bus, intermediate and line-end faults. The fault connection can be single-, two- and three-line-to-ground and line-to-line. Branch-outage and remote-end-open options are available to all fault types. The fault capability of *OneLiner* far exceeds that of the *Philadelphia Electric Network Fault Analysis Program*. However, *OneLiner* still does not have the capability to simulate simultaneous faults, which is available in the mainframe *ASPEN Short Circuit Program*.

The fault simulation time with *OneLiner* is remarkably fast. Most single faults on the SPPCo system require only one second to complete. Displaying results on the screen is equally fast. Simulation results can be viewed in many forms:

- on-screen graphical one-line diagrams
- on-screen graphical relay characteristics
- on-screen tabular outputs
- plotted and/or printed one-line diagrams
- plotted and/or printed relay characteristics
- printed tabular outputs.

Post-fault voltages and current contributions up to eight tiers from the fault can be shown on screen. (More tiers can be displayed for a smaller system.) See Figure 3. This is in sharp contrast to most short circuit programs that provide output in a tabular form only. A nice feature of the fault simulation display is that the current shown next to the faulted relay group for a close-in fault is the actual relay current. The tabular printouts of most short-circuit programs report only the branch currents, assuming that the fault is at the bus (and not in front of the relay). To get the relay current for a close-in fault, the relay engineer must compute it based on the total fault current and the various branch contributions — a tedious process at best.

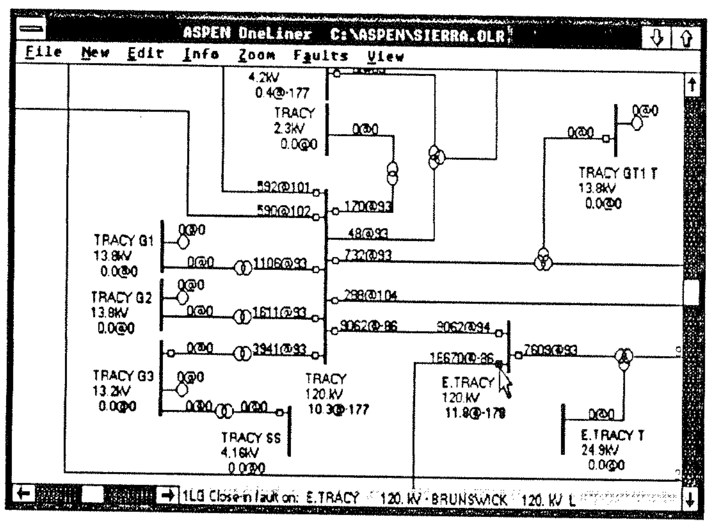

Figure 3: Results of a fault simulation being displayed on the one-line diagram. The zero-sequence voltages are shown under the bus names and the zero-sequence current (3Io) are shown on the branches.

ONE-LINE DATA MANIPULATION

Circuit Elements

Data management with *OneLiner* is far easier than with other programs. Whereas most short circuit programs require the data to reside in specific columns in a text file, the data in *OneLiner* are presented to the user in the form of Info dialog boxes. Within the dialog box, each data item is shown either as text in an edit box or as options represented by buttons, check boxes and list boxes. Column alignment is never necessary. With *OneLiner,* typing on the keyboard is used only for entering parameters on a dialog box and for "keyboard accelerators", which are shortcuts for clicking the mouse on the menu items.

To review or modify object parameters, the user first opens the Info dialog box for the object by double-clicking the mouse near the object's symbol on the one-line diagram. As an example, Figure 4 shows the dialog box for a two-winding autotransformer. Once the dialog box is opened, the user can change the parameters by typing over the text in edit boxes or by clicking on the available buttons, check boxes and list boxes. All the parameters and options of a circuit element are displayed in its Info dialog box. Gone are the problems of entering data in the wrong column (and having the program return a cryptic error message, or worse, having a 1.0 p.u. impedance interpreted as 10 p.u.), and hunting through a thick manual for the correct data format. Similar dialog boxes exist for other circuit elements.

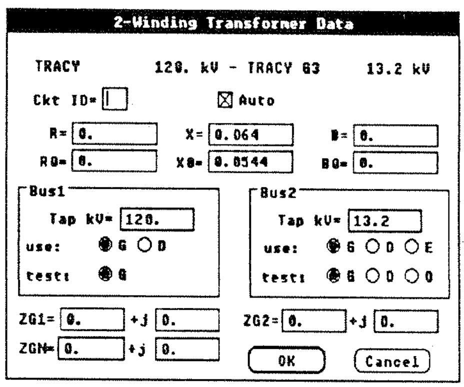

Figure 4: Info dialog box of a 2-winding autotransformer.

The user can move any symbol on the one-line by pressing the mouse button near the symbol and moving the mouse with the button held down. This is called "dragging". The symbol will appear to move with the mouse as if being dragged physically. When a bus is moved, the program automatically moves other elements directly connected to the bus.

Deleting objects with *OneLiner* is simple compared to other programs. The user must select an object by clicking the mouse on its symbol, then issue a "delete" command through a pull-down menu. Circuit elements can be temporarily deleted to duplicate special switching conditions and later restored with the "Restore" command. Adding a component is similar. The user highlights a bus, or busses, with the mouse and uses the pull-down menu to select the device required. Figure 5 shows how to add a transmission line to the network. Whenever a network element is added to or deleted from the one-line diagram, the network model is updated automatically. There is never a discrepancy between the graphical representation of the network and the underlying network model — what you see on the one-line diagram is truly what you get.

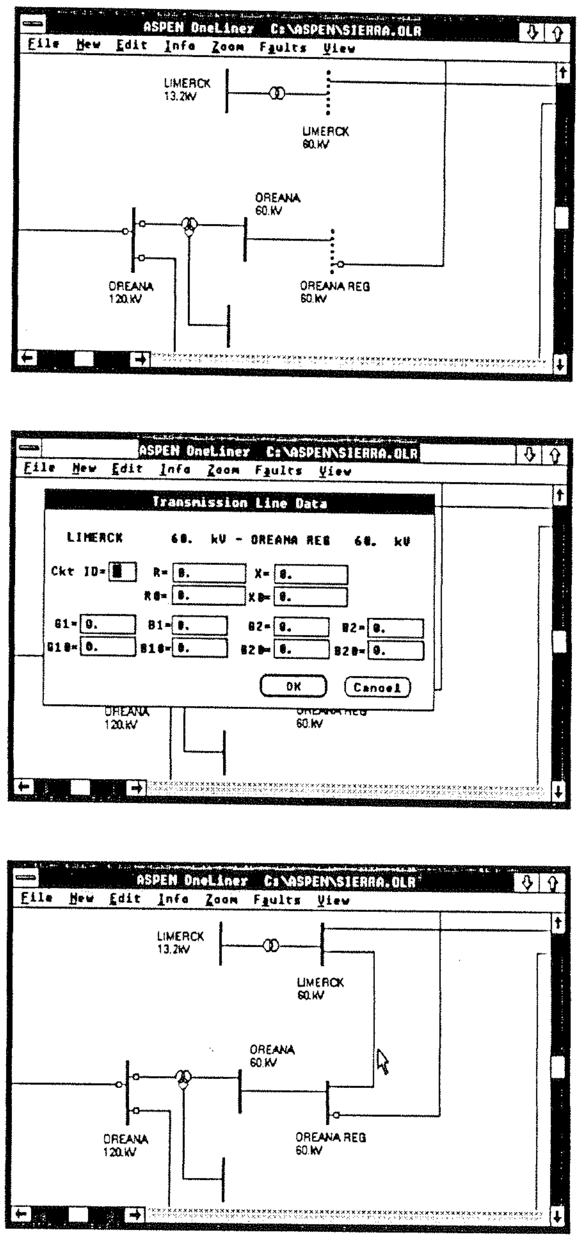

Figure 5: Adding a new line between buses Limerck 60kV and Oreana Reg 60kV requires (1,top) selecting the two end buses, (2,not shown) clicking on the New Line menu, and (3,middle) entering the new line's parameters. (bottom) The new line is created when the dialog box is closed.

Relay Characteristics

Up to now, only circuit elements in the one-line diagram have been discussed. They are only half the program; protective relays are the other half.

Relays that protect a branch are stored in a relay group, the symbol of which is a small square resembling a circuit breaker. *OneLiner* models three types of relays: overcurrent (phase and ground), distance (phase and ground) and fuses. Any number of relays can be put into a relay group. The user can call up information on a relay and modify its parameters the same way as any other network element.

Figure 6 shows the dialog box for specifying the settings of a ground overcurrent relay. All overcurrent relay settings, such as pickup tap and time lever, can be specified. For a directional relay, the user must enter a characteristic angle, which is the displacement of the maximum torque angle relative to the polarizing quantity. Figures 7 and 8 show the dialog boxes for distance relays and fuses.

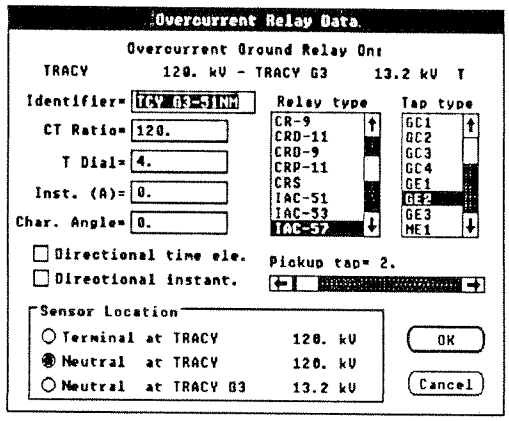

Figure 6: Info dialog box of an overcurrent relay.

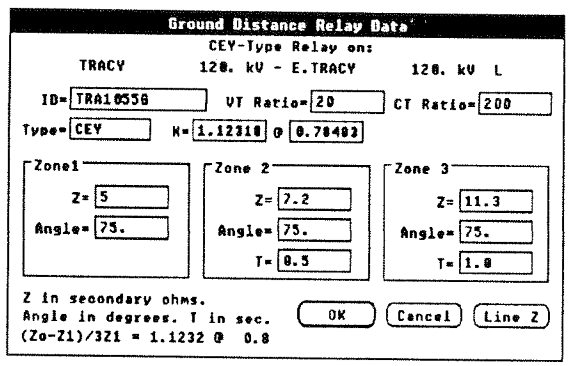

Figure 7: Info dialog box of a distance relay.

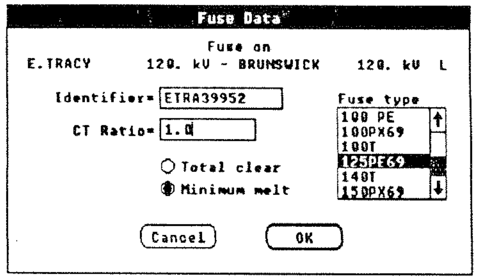

Figure 8: Info dialog box of a fuse.

RELAY COORDINATION

The time-honored "hand" method of overcurrent relay coordination is well known to relay engineers. In this method, every relay, fuse, and transformer and conductor damage curve is carefully plotted by hand on time-current characteristic (TCC) graph paper. When plotting, a number of questions may arise: what current base should be used to calculate the pickup shift ratio? Additionally, have all ratios been computed correctly? Have delta-wye transformations been accounted for? Are directional units polarized in the reverse or forward direction? All these questions are answered by *OneLiner,* which does not automatically coordinate relay settings, but streamlines an otherwise time-consuming task.

Up to twelve overcurrent relay and damage curves can be displayed on the screen on the familiar log-log plot. For any given fault, the relay curves can be shown either shifted (based on the ratio of the relay current to the total fault current) or unshifted. See Figure 9 for an example of shifted relay curves, which is the form most commonly used at SPPCo. *OneLiner* is fast and accurate. The relay currents and voltages are always computed exactly, taking into account all infeeds, phase shifts and transformer ratios. Gone are the pitfalls of the hand method.

OneLiner really shines when playing "what if" games with relay settings. Double-clicking the mouse on the description box of a relay brings up that relay's Info dialog box (Figure 10). Any changes are immediately updated on the graph upon closing the dialog box.

Relay operating times can also be shown on the one-line diagram. See Figure 11. The user can select one of three options: overcurrent relay only, distance relays only, or all relays. If a relay group has more than one relay, the time shown is from the fastest relay of the type (or types) selected in the group. The user can bring up a relay's Info dialog box and modify any relay settings. New operating times are instantly displayed on the one-line diagram when the Info dialog box is closed.

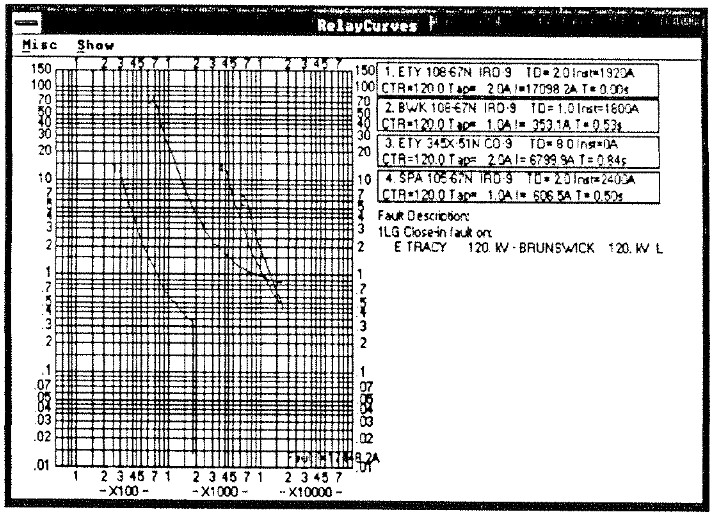

Figure 9: Shifted relay curves for a fault. The total fault current (about 17,000A) is shown just above the horizontal axis. All the curves are shifted by the ratio of relay current to the total fault current.

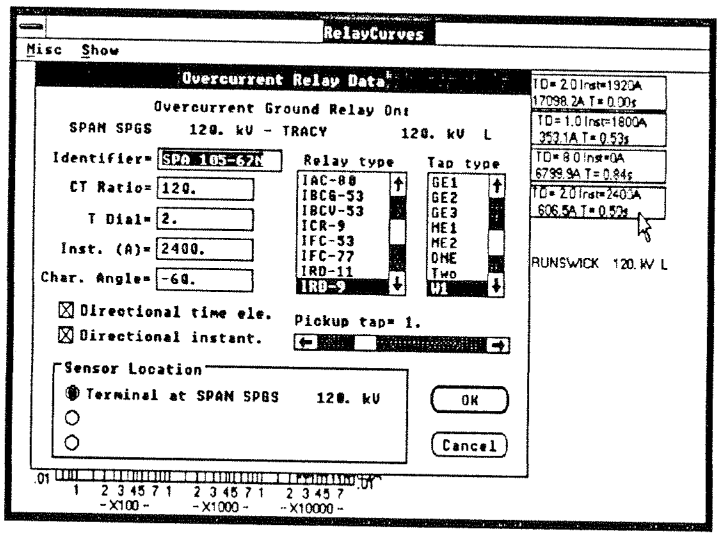

Figure 10: Double-clicking on a relay's description box brings up that relay's Info dialog box. The relay curve is automatically redrawn to reflect the new settings when the dialog box is closed.

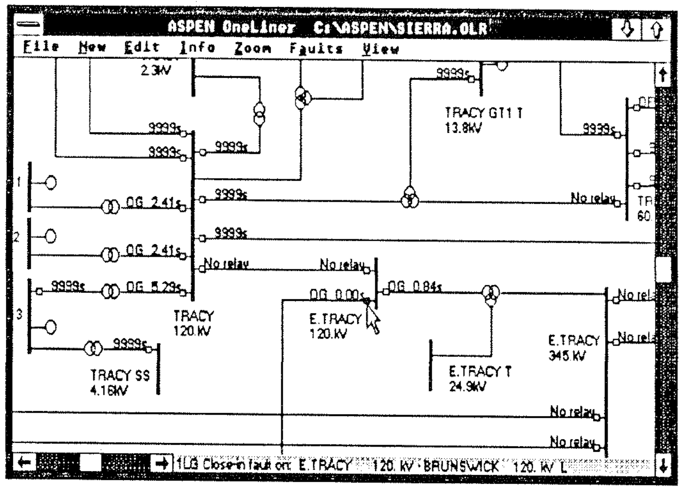

Figure 11: Relay operating time shown directly on the one-line diagram. The operating time preceded by "OG" if it is from an overcurrent ground relay, "OP" if it is from an overcurrent phase relay, and "FU" if it is from a fuse.

The coordination of distance relays is immediately apparent by viewing the relay operating time and zone number directly on the one-line diagram. See Figure 12. The user can change settings of the distance relays likewise and see the new relay operating time and zone numbers on the one-line diagram.

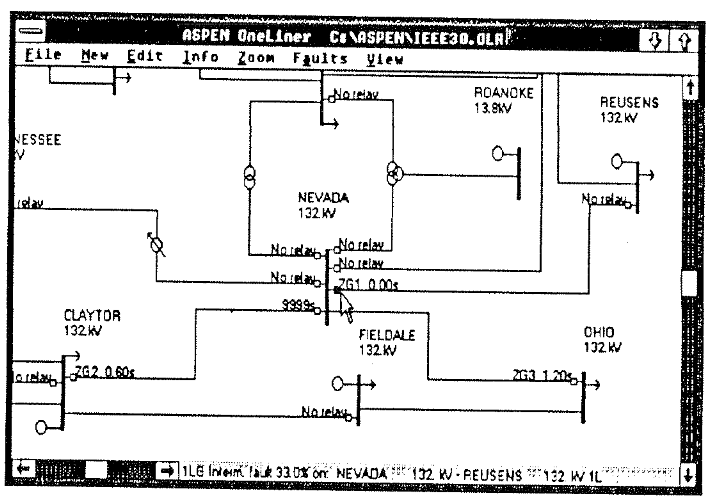

Figure 12: The distance relays' zone numbers and operating times are being shown on the one-line diagram. The label "ZG1" means that the operating time is from zone 1 of a distance ground relay. "ZG2" and "ZG3" refer to zones 2 and 3, respectively.

The operations of a distance relay can also be displayed on the complex plane. For example, intermediate faults simulated on an adjacent line can be plotted to determine relay reach (Figure 13). Previously, quantifying infeed was difficult for faults on an adjacent line. The computation is quite formidable for faults that are more than two tiers away. This is not a problem in *OneLiner* because the program always computes the relay operate quantities based on voltages and currents at the relay location.

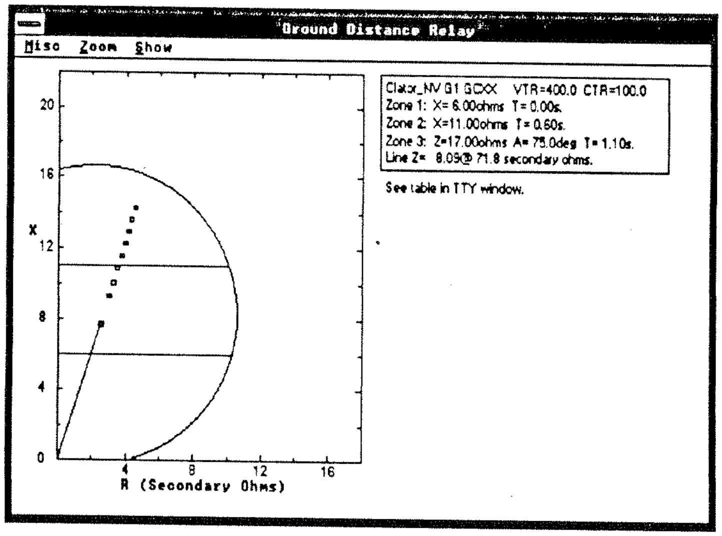

Figure 13: The impedances of nine intermediate faults (10%, 20%,...,90%) on an adjacent line are superimposed on a distance relay's characteristics.

CONCLUSION

OneLiner is a powerful tool for the relay engineer. It relieves the relay engineer from the tedious and time-consuming tasks of leafing through stacks of printouts, plotting relay curves, and drawing and labeling one-line diagrams without taking away the decision-making role from the engineer. At SPPCo, the program has allowed relay engineers to produce coordination results in one-third the time required by the traditional hand method and, at the same time, reduce the possibility of errors.