Computerised Protection Coordination and Contingency Analysis for Transmission and Distribution Systems

by B. J. Seshaprasad and Jim Wilks

Synopsis

The design and maintenance of protection systems for transmission and distribution networks makes heavy demands on the time of highly skilled technical personnel.

This paper describes the basis for the design and implementation of a time and resource saving integrated software package that combines the ability to calculate fault currents and their distribution in a network with the capacity to suggest protective devices settings/ratings to achieve coordination. The interactive and menu driven software has been implemented on popularly used personal computers. The features of the software include screen based data input/edit, graphical display of characteristic curves and display of protection operating times for various contingencies.

Two case studies involving typical sub-transmission and distribution applications are used to illustrate the capabilities of this type of software and the substantial productivity gains obtainable.

1. INTRODUCTION

One of the most important requirements of electric power system operation is to isolate and disconnect faulted parts of the system selectively and quickly. This can only be achieved by well designed and maintained protective systems.

The basics of protection design and maintenance are taught as part of undergraduate courses in electrical power systems engineering, but proficiency in this field is normally only gained after a number years of practical experience and specialist studies and/or training. As a result, most of the manual work on protection design and maintenance is, inevitably, a heavy consumer of an increasingly scarce and expensive resource - the time of highly skilled specialist engineering and technical personnel.

Today most electricity supply utilities, power intensive industries and engineering consultancies operate under tight constraints on staff numbers and levels and expenditures ... and the only likely change in the near future is for these pressures to increase!

In these circumstances it is imperative that any available productivity enhancing tools are used to increase the output and effectiveness of protection design and maintenance staff.

The power of low cost desktop computers (with computational powers equivalent, or even exceeding, that of mainframe computers of only a few years ago), when combined with modern software development techniques, has made it possible to have highly cost-effective and sophisticated software tools available for staff designing and managing protection systems.

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With a number of personal computer based software packages now available for protection staff, this paper examines the design philosophy and features of an Australian developed package winning regional and international acceptance. It also demonstrates the level of productivity improvements obtainable from the use of this type of software and surveys the trends in the development of protection co-ordination software generally.

2. PROTECTION SYSTEM DESIGN USING COMPUTERS

Over-current relays and fuses with inverse time characteristics are still the most commonly used protective devices used in electricity distribution systems and industrial power systems. They are also still widely used in sub-transmission systems, though in these more complex and higher-voltage networks they are generally only part of other more sophisticated protection systems.

The process of coordinating these devices can be very tedious and time consuming. However, the application of the computer to this process helps to greatly improve the efficiency of staff engaged on these activities.

Early efforts in the area of over-current relay coordination were essentially directed towards complex computer programs, with comprehensive algorithms for worst case settings for large interconnected transmission systems [1]. Most of these programs were developed for in-house usage on large mainframe computers. Also, they were not usually integrated with a fault calculation program.

In retrospect, these programs did not become popular partly because they were complex in-house programs, but also because over-current relays gave way to distance relays as primary means of protection in the case of high voltage transmission systems. Consequently, most relay setting calculations for over-current devices are still done manually.

More recently, however, there has been a resurgence in the development of methodology and computer programs in the area of over-current relay coordination. A comprehensive report on the specification of computer aided design of transmission protection systems has been developed as part of an EPRI project.[2,3] The arrival of powerful personal computers has also led to an upsurge in the development of computer programs[4] tailored mainly for the requirements of utility and industrial distribution networks.

A major project - recently sponsored by 10 major US electric utilities - is the development of a Computer-Aided Protection Engineering (CAPE) system incorporating a comprehensive protection system database, database editor and eight analysis & reporting modules.[5] (However this complex and very sophisticated system is based on the use of an engineering workstation rather than a personal computer.)

3. COORDINATION SOFTWARE DESIGN CONSIDERATIONS

3.1 User-friendliness

While the power of personal computers has made fast and accurate protection calculations readily accessible, what distinguishes between protection coordination software packages is their basis of operation and their degree of user- friendliness.

Too often engineering software seems to assert its degree of "cleverness" by presenting itself to the user so that only the most dedicated specialist user can ever master it. However, the design of the software package presented in this paper (*RELCORD*), is aimed at not only providing direct benefits to experienced specialist users, but to also aid the non-specialist users and less experienced staff to the extent that they might undertake tasks, albeit with some expert guidance, that may previously have seemed to be beyond their capabilities.

An over-riding consideration in the design and implementation of the software is to assist users as much as possible - without the need to remember cryptic codes, bus numbers, etc. - and to maintain a suitable balance between the sophistication of the program and the complexity as experienced by user.

Fundamental to its ease-of-use and productivity enhancement ability is its *complete integration* of *fault analysis* procedures with the capacity to study overcurrent *protection coordination*. To this is added the ability to suggest settings to achieve user-set discrimination conditions and to report protection operating times, if any, for any user-nominated fault - of any type - anywhere on the system - and under any system operating condition.

It was also a requirement that its operation be able to be quickly learnt ... and readily recalled if the user does not work with it for some time.

3.2 Modelling Device Characteristics

A fundamental issue for over-current device coordination using digital computers is the method of representing protective device time/current characteristics.

Traditionally, this has been done by modelling characteristics by fitting a mathematically defined curve to data points taken from the device characteristic. However there are now also some other options.

3.2.1 Polynomial Modelling

One of the earliest works in this area was done by Radke [6] .. and more recently by Smolleck[7] ... which discusses in detail the method of obtaining the computational models for time-current characteristics.

The following equation suggested by Radke is adequate to model many time-current characteristic curves:

$$\log(t) = \Sigma_{i=0}^{N} a_i [\log(m)]^i \qquad \text{... (1)}$$

where

t = device operating time at a given time/lever setting in seconds
m = multiple of tap current setting
a_i = polynomial coefficient
N = order of the polynomial

From experience, a polynomial of 5th or 6th order is adequate for many commercially available relays.[8]

The polynomial modelling technique has the advantage of being computationally efficient using a simple algorithm and needing only limited data storage for the curve - ie. only the curve polynomial coefficients.

Modelling does need to be done with some care as, in some instances, models that seem accurate (with a good match between the fitted curve and the data points) may actually deviate substantially from the characteristic between data points - especially if a high order polynomial is used.

3.2.2 Spline Modelling

The cubic spline model has the advantage that the fitted curve will, by definition, pass through all the data points and curve "naturally" in between. Generally this results in a smooth curve and this model is well suited to many characteristics - including fuses and some other discontinuous curves not able to be satisfactorily modelled by a polynomial.

However, the spline model requires more data storage - all data points have to be stored - and is much more computationally intensive than the polynomial model.

Though it will handle discontinuities, abrupt changes can cause the fitted curve to oscillate through nearby points unless the curve is constrained by extra data points around the change. Some experimentation may be required to achieve the required accuracy in these circumstances.

3.2.3 Formula Definition

International Standards IEC 255 and BS 142 prescribe a formula that is used to define the time/current relationship for a number of standard characteristic curves.

These curves, known as the *Inverse*, *Very Inverse*, *Extremely Inverse* and *Long-time Inverse*, are in agreement with the similarly named characteristics well known in the field of protection for many years.

The formula is directly implemented by many electronic and micro-processor controlled protective devices and closely matches the characteristics of a number of electro-mechanical devices. In fact, these formulae can be used to accurately represent the characteristics of a number of popular electro-mechanical relays from different manufacturers.

The general form of the formula and the constants used to define the different characteristics are:

$$t = k \cdot \frac{\beta}{\left(\frac{I}{In}\right)^{\alpha} - 1} \qquad \text{... (2)}$$

where:

t = operating time (seconds)
k = time multiplier
I = device current (amps)
I_n = tap/current setting (amps)

Characteristic Curve	α	β
- Inverse	0.02	0.14
- Very Inverse	1.00	13.50
- Extremely Inverse	2.00	80.00
- Long-time Inverse	1.00	120.00

3.2.4 Other Characteristic Representations

In addition to the methods described above, other options for representing characteristics include variations on the above polynomial formula (Equation 1), modelling with B-Splines and Bezier curves and other formula definitions eg. by run-time parsing and evaluation of user-entered formulas.

3.2.5 Time Settings

For protective devices with a range of time settings (or lever settings) curve fitting is traditionally done for the device characteristic corresponding to the highest time setting and the operating times at other time/lever settings are obtained as a proportion. This is often known as the "template" method.

The template method essentially assumes that the operating time is linearly proportional to the lever setting. In practice, such an extrapolation is not always accurate, especially at low values of tap current multiples. Hence, conservative values of discrimination times have been employed by protection engineers to allow for such errors.

For most standard types of inverse time characteristic devices more accurate simulations of device operating times can be obtained by calculating and storing polynomial coefficients for maximum, middle and minimum time/lever setting characteristics and interpolating as needed.

3.2.6 RELCORD's Representation of Characteristics

RELCORD accesses a database of protective devices and the management of the database is carried out with a utility program known as *DEVICEDB* - a standard part of the software package. It allows the user to determine the devices to be accessible at run-time and to model new devices to add to the database. As well it allows the user to check and edit details of existing devices and view on screen a plot of the representation of the characteristic curve. Where a curve is fitted to data points it also shows the data points on the plot so the user can see the accuracy of the fitted curve.

With this utility the user can also calculate operating times (according to the characteristic representation) for any nominated time settings and current values or, conversely, to determine time/lever setting corresponding to a particular operating time.

The user can choose to represent characteristics by:

- Polynomial Modelling
- Cubic Spline Modelling
- Formula Definition in accordance with IEC 255 and BSS 142

Polynomial modelling is carried out by entering time and current coordinates from the characteristic curves (or family of curves) and using a least square algorithm to derive the polynomial coefficients for a curve fitting the data. The order of the polynomial to be used to model the characteristic can be set by the user as needed to achieve a sufficient level of accuracy (up to a maximum of 9).

For devices with a range of time/lever settings, polynomial coefficients are stored for maximum, middle and minimum time/lever setting characteristics. The operating time at any intermediate time/lever setting is determined by interpolation between the maximum, middle and minimum curves using a second order Newton's interpolation method.

With the polynomial method many of the commercially available relays and other protective devices have been modelled with errors typically less than 1.0%.

Cubic spline modelling also requires data points to be entered from the characteristic curve of the protective device and the actual data points are stored. The spline curve coefficients are calculated at run-time to allow operating time interpolations.

Formula definition is supported for *Inverse, Very Inverse, Extremely Inverse* and *Long-time Inverse* - characteristics in accordance with the IEC and BS Standards and for variations in the constants used in the standard formula. When this option is chosen no curve fitting is carried out - the program calculates operating time directly from the standard formula as the actual protective device does so no modelling errors are incurred.

3.3 Protection Coordination

The coordination process involves computation of two settings, namely the current or tap setting and, where available, the time or time lever setting for every device in the system. The current (tap) setting determines the current multiplier for a given current flowing through the device and the time setting specifies the particular time-current characteristics from the family of available curves to be used to find the device operating time .

The current (tap) settings are chosen in such a way that the devices do not operate under normal operating conditions. Typically the settings are based on the maximum expected short time load current in the case of over-current devices, or the maximum expected unbalance current in the case of earth fault relays. So the current (or tap) setting is found from:

$$\text{Current Setting} = \frac{\text{Maximum Load/Unbalance Current}}{\text{Current Transformer (C.T.) Ratio}} \quad \dots (3)$$

The setting chosen is the next higher available setting for the device in question. This current/tap setting is used unless a higher setting becomes necessary for coordination as a Backup Device.

The time/lever settings are established to provide adequate selectivity between devices under fault conditions. In other words, the device nearest to the fault should operate first. Such a device is referred to as the "Primary Device". In order to allow for the contingency of protection gear failure, the device next closest to the fault ("Backup Device") is set to operate after a specified time delay ("Discrimination Time").

The process of calculating the time/lever setting is straight forward in the case of a purely radial system. Typically, the device farthest from the source is assigned the minimum time/lever setting and the time/lever setting for the backup device is established by considering a fault at the terminals of the primary device breaker. This process is repeated till the time/lever setting of the device closest to the source is found.

However, the process of coordination becomes much more complicated in the case of a meshed system or even in the case of radially operated systems with parallel feeders. Typically time/lever setting calculations would need several passes through the set of device pair data, to obtain the final settings.

The following procedure is used to calculate the time/lever settings in a systematic way.

1. Identify the set of "Device Pairs", namely the combination of Primary and Backup devices which need to be coordinated. This simple process is carried out by the user by inspection of the network. The devices identified are entered in the "Device Pair" data along with the fault type, fault impedance, fault location(s) to be considered and the required discrimination time for each device pair.
2. Initially set the time/lever settings of all devices to minimum available settings. (See initialising of time/lever setting below).
3. Scan each device pair sequentially and calculate the new time/lever setting for the backup device based on the operating time of the primary device plus the discrimination time specified for the device pair.

   By default the new time/lever setting for the backup device is calculated based on the first, or both, of the following primary device feeder fault conditions:

   (a) a fault *close* to the primary device breaker terminals with the *far end breaker open*.

   (b) a fault on the *far* end of the primary device feeder with the *far end breaker closed,*

   When both of the above fault conditions have been nominated by the user the higher value of the time/lever for the two is taken as the required time/lever setting of the backup device.

   The program logic automatically considers maximum phase current in the case of overcurrent devices and unbalance current in the case of earth fault relays.
4. The time/lever settings of the backup device is updated only if the calculated time/lever setting in Step 3 is greater than the existing time/lever setting. If maximum time/lever setting is reached, then the next higher tap for the backup device can be set interactively by the user

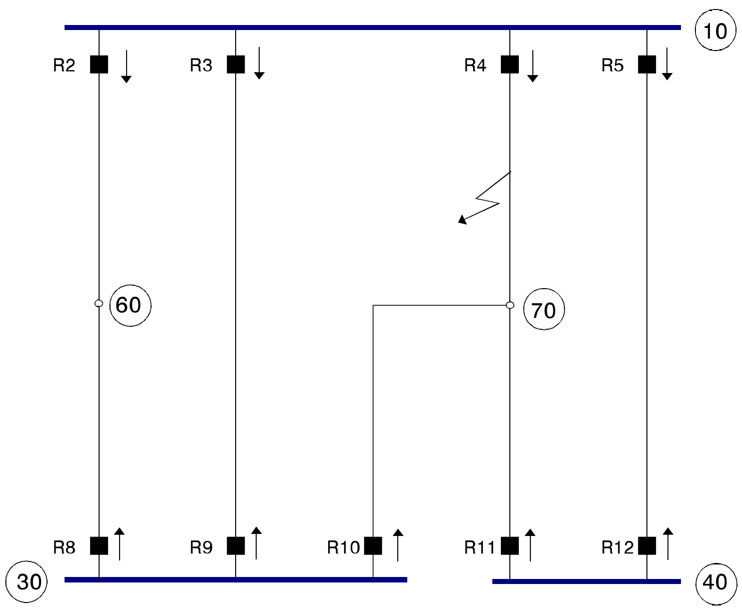

Figure 1. *Sub-transmission case Study System*

5. Steps 3 and 4 are repeated for each device pair in turn, till no change is required for any of the backup devices in the device pair data.

In a typical distribution system, the final time/lever setting is obtained within a few iterations.

Apart from the general procedure described above, the program will bypass the tap/lever setting calculations for any devices that have been flagged as "Fixed" by the user. This feature enables the user to nominate unchangeable settings (eg. fuses) and to interactively coordinate devices in special circumstances not covered by the program logic.

The user can also change the device type interactively, through a simple edit process, to any device type currently included in the device database, if necessary.

While calculating time lever settings, the option is given of initialising all time/lever settings to minimum value or, starting the analysis with the existing settings. This feature is very useful for checking the device coordination in an existing system. The backup device time/lever setting is changed by the program logic only if the discrimination time is inadequate for the device pair in question. Any devices that needed a change in time/lever settings is flagged with a "*" in the program reports to help identification of changes made (See Figure 3.) When beginning a new coordination study it would be usual to elect to have all devices initialised to minimum time/lever settings to ensure that all settings suggested are the minimum obtainable.

It should be noted the above coordination process is carried out using faulted conditions on the primary device feeder. However, if the primary device has more inverse characteristics than the backup device, the discrimination may not be adequate at lower values of current. Such a condition becomes evident when device characteristics are plotted for each device pair or can be revealed by a contingency check (see Section 3.4). In such cases, coordination can be achieved either by increasing the discrimination time for fault currents or by reducing the fault current by using appropriate fault impedance. This problem is typically encountered when coordinating over-current relays with fuses.

3.4 Contingency Analysis

One of the powerful features of an integrated faul analysis <u>*and*</u> protection coordination program is tha the operating time for protective devices can be checked for various operating conditions and contingencies.

Contingencies that can be checked include:

- changes in the network through various parts of the system (feeders, transformers etc.) being in or out of service - for example, due to operational changes or outages - and
- the occurrence of varying types of faults (particularly faults of types different to that used for determining the coordination settings) <u>*anywhere*</u> on the network, including meshed networks with paralleled feeders and transformers.

The fault can be either a bus fault or a line fault at any location in the network.

This facility - illustrated as part of the Case Studies in Section 4 - is also very useful for reviews of protection performance after actual faults have occurred.

3.5 Plotting Coordination Curves

The primary output of a protection coordination program is the current (tap) and time (lever) setting for all devices - and plots of characteristic curves corresponding to the settings. Curves should be able to be viewed on screen or produced as a hard-copy record on a plotter and/or printer. Ideally, the program should also allow the display of the device operating times for a specific fault condition and the graphic display of characteristics for selected devices.

In *RELCORD,* coordination curves of up to six devices can be viewed concurrently on the screen or be output to a printer, plotter or saved to disk as a plot file. The choice of devices to be included is by a user selected "Device List". When the results of a contingency analysis involving the application of a fault on the network are plotted, it includes a plot of the fault current ordinate and a listing of the protection devices in the device list showing the fault current seen by each device and its operating time, if any. (see Appendix A.)

Separate plots of the characteristics for the pairs of devices in the device pairs list are also available.

4. APPLICATION CASE STUDIES

4.1 Sub-transmission Application

The system for over-current device coordination has been selected from an actual electricity utility network and is as shown in Figure 1. The network is rather complex from the point of view of device coordination because of the parallel and interconnected feeders, but also as there are no less than 11 device pairs to be coordinated.

The device pairs are entered by the user in the Device Pair Data (see Figure 2.)

RELCORD- Relay Coordination V5.15c (300 Bus) 04/06/93 14:10

EDIT RELAY PAIR DATA (Over-Current Rela

Primary Relay	Backup Relay	Discrim'n [Secs]	Fault Type [1/2/3 Ph]	..Fault Impedance.. R [p.u.]	X [p.u.]	Fault Locatio [Close/Both]
R8	R3	.40	3	.00000	.00000	B
R8	R4	.40	3	.00000	.00000	B
R8	R11	.40	3	.00000	.00000	B
R9	R2	.40	3	.00000	.00000	B
R9	R4	.40	3	.00000	.00000	B
R9	R11	.40	3	.00000	.00000	B
R10	R3	.40	3	.00000	.00000	B
R10	R2	.40	3	.00000	.00000	B
R11	R5	.40	3	.00000	.00000	B
R12	R4	.40	3	.00000	.00000	B
R12	R10	.40	3	.00000	.00000	B

Enter Data :

Esc-Exit Ins-Insert Del-Delete F3-Search F1-Help

Figure 2. *Device pairs for the Sub-transmission case Study*

RELCORD- Relay Coordination V5.15c (300 Bus) 04/06/93 14:00

TAP/LEVER SETTINGS (Overcurrent Relay)

STUDY TITLE : ESEA Paper Case Study 2

Relay Ref	..Relay Location.. RlyBus	RemBus	Ckt	..Relay Type..	C.T.Ratio Pri / Sec		Tap Setting	Lever Setting	
R2	10	60	1	CDG11-1.3	100.0/	1.0	1.00	.410	*
R3	10	30	1	CDG11-3.0	100.0/	1.0	1.00	.220	*
R4	10	70	1	CDG11-1.3	100.0/	1.0	1.00	.330	*
R5	10	40	1	CDG11-3.0	100.0/	1.0	1.00	.180	
R8	30	60	1	CDG11-1.3	100.0/	1.0	1.00	.100	
R9	30	10	1	CDG11-1.3	100.0/	1.0	1.00	.100	
R10	30	70	1	CDG11-1.3	100.0/	1.0	1.00	.260	*
R11	40	70	1	CDG11-1.3	100.0/	1.0	1.00	.190	
R12	40	10	1	CDG11-1.3	100.0/	1.0	1.00	.100	

Press any key to Continue or ESC to Exit

Figure 3. *Device settings for Sub-transmission Case Study*

For this case study the discrimination times for all device pairs are set arbitrarily to 0.4 second and a three phase fault is considered for all devices to be coordinated.

Once the required data is available as disk files, it takes only the typing of a simple and logical sequence of single key commands to carry out a device coordination study session. The device settings obtained after analysis are shown in Figure 3.

Contingency Analysis: The program allows equipment to be put in or out of service through a simple edit process so worst case settings can be obtained in a simple way by repeating the coordination procedure for various contingencies.

For any network contingency the user may have the program either :

- recalculate new time lever settings to achieve coordination, if possible, based on the contingency conditions, and/or
- calculate the protection operating times for a nominated fault anywhere on the system operating under whatever system conditions now exist

For example, for this case study a three phase fault part way along the line from Bus 10 to Bus 70 while the feeder from Bus 10 to Bus 30 is out of service (see Figure 1.) can readily be simulated by using the "On/Off status" feature in the Feeder Edit module of the Fault Analysis section of the program.

The protection operating times for the current network condition and protection settings can then be calculated and displayed. This additional report takes only a few keystrokes to initiate and just a few seconds to calculate.

The report output from this contingency analysis in tabular form is shown in Figure 4. The same analysis results can also be output to a plotter (see Appendix A and Section 4.2).

It can be noted that relays R2, R3 and R5 are backup relays and the actual currents flowing through the relays are also displayed. With this information available users can easily check the operating time from manufacturer's device curves to verify results while gaining confidence in the program results.

The procedure of recalculating settings can be repeated by simulating further single or multiple contingency conditions. If the discrimination is not adequate, the new device settings can be obtained by repeating the activity for calculation of Backup Device time/lever settings for the contingencies.

The program logic uses the base case settings as reference and changes the device settings only for relays for which the discrimination is not adequate. Hence, the program logic provides worst case settings that are suitable for the base case and the contingencies analysed.

4.2 Distribution Application

Distribution systems almost exclusively use over-current type protection - such as high and low voltage fuses, over-current and earth fault relay controlled circuit-breakers, reclosers, etc.

This case study illustrates protection coordination of a typical distribution feeder originating from a zone substation in a largely urban area and extending into a large rural area with a voltage regulator, a number of reclosers, sectionalisers and fuses of varying types and sizes. The diagram (Figure 5.) is a simplification of an actual feeder.

The design and management of the protection of this feeder involves establishing and periodically reviewing the settings/ratings of protective devices for the feeder according to changes in the magnitude of loads, and changes of operational requirements.

Other irregular reviews may also be prompted by the addition of spot loads or new extensions to the feeder.

Contingency Analysis: Distribution feeders may require additional analysis.

For example, in this case study of a long feeder extending into a rural area, the fault levels at the ends of the feeder are so low that fault currents may only be of the same order of magnitude as load currents at other nearby parts of the feeder. So a careful analysis of *minimum fault*

RELCORD- Relay Coordination V5.15c (300 Bus) 07/06/93 09:11

RELAY OPERATING TIMES (Overcurrent Relay)

STUDY TITLE : ESEA Paper Case Study 2

Three phase fault on line Bus-10 [10] to Bus-70 [70] Ckt 1

Distance to Fault from Bus : 50.0 %

Relay Name	...Relay type...	Relay Amps	C.T. Ratio Pri / Sec		Tap Setting	Lever Setting	Relay Op.Time
R2	CDG11-1.3	272.47	100.0	1.0	1.00	.410	.99
R3	CDG11-3.0	.00	100.0	1.0	1.00	.220	*****
R4	CDG11-1.3	2074.73	100.0	1.0	1.00	.330	.34
R5	CDG11-3.0	276.42	100.0	1.0	1.00	.180	1.15
R10	CDG11-1.3	272.47	100.0	1.0	1.00	.260	.60
R11	CDG11-1.3	276.42	100.0	1.0	1.00	.190	.43

Press any key to continue

Figure 4. *Device Operating Times for Contingency.*

conditions is needed *as well as* the usually more onerous maximum fault conditions - particularly for earth fault conditions.

RELCORD's ability to deal with the coordination of both over-current and earth fault protection is advantageous for this type of analysis.

Typical contingencies needing to be examined as part of this case study include checking the effect of :

1. Supplying the feeder from the alternative source of supply by-passing the first recloser,
2. Operating the 66/11kV transformers in parallel,
3. Application of a high resistance fault at the end of the steel conductored single phase spur at the end of the feeder
4. A recloser being out of service,
5. Feeder load growth, etc.

Figure 6 shows the on-screen display of a group of characteristics for the suggested settings for this case study.

The results of a contingency analysis on this system involving the occurrence of a high resistance fault at the end of the long single phase spur are shown in Figure 7 - the user also has the option of producing a plot in the same format as the example shown in Appendix A.

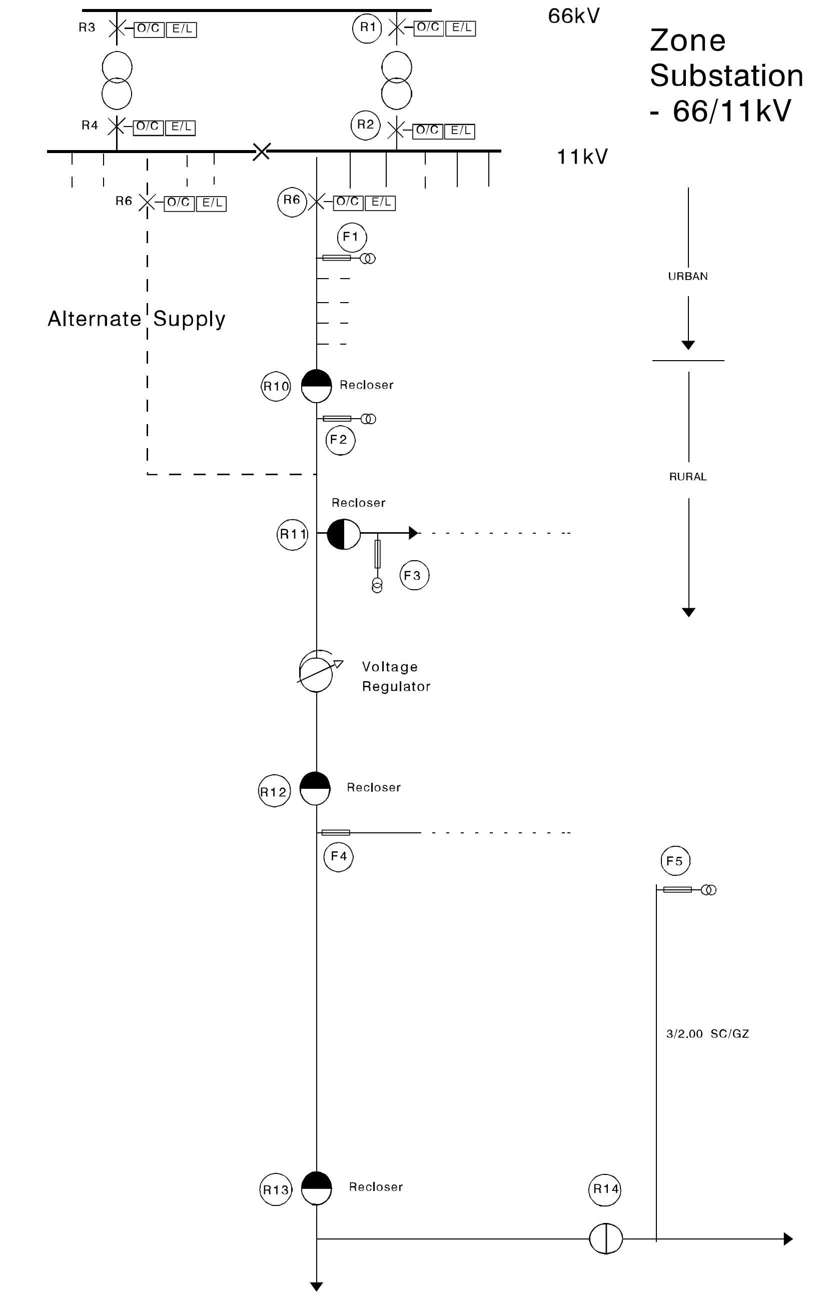

Figure 5. Distribution Case Study System

5. PRODUCTIVITY GAINS

The real value of modern protection coordination software is seen when the time taken to carry out actual assignments is examined. And the more complex the system, the more dramatic are the benefits.

After collection of the basic data that is a common requirement for either manual or computer-aided analysis, the actual computational time using a program such as *RELCORD* is negligible.

The computation time taken for backup time/lever coordination, including the required fault calculations for each the sub-transmission and distribution case studies takes only a few seconds on a 80386 or 80486 computer commonly used in many engineering design offices.

The calculation times of each complete session of coordination studies for the case studies took only a few minutes.

Even if the time required for initial data entry is taken into account the whole exercise can be completed in less than 1 hour. And once the data has been entered and saved to a disk file, for any future review of the protection all that will be needed is to reload the data file and simply edit the data to reflect any changes.

From the authors' experience, these studies can take up to 2 weeks if carried out manually without a fault program. Even with access to a fault program the studies would still take 2 or 3 days.

Since most device coordination work in distribution utilities and industrial power systems is still being carried out manually there is great scope for improving productivity in this activity with *the bulk of the work* of even complex studies being reduced from days, or weeks, to just hours ... or even less.

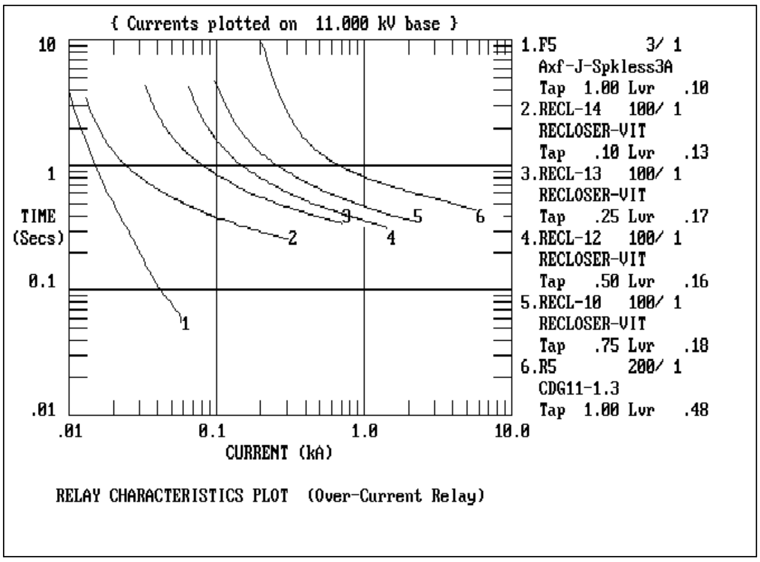

***Figure 6**. On-screen display of group of characteristics*

6. TRENDS IN PROTECTION COORDINATION SOFTWARE

6.1 Present software

Currently available software for protection design and management falls into 4 main categories:

1. Curve plotting utilities

Typically these programs (or program modules) access a database of characteristics of protective devices and allow the user to nominate settings for devices etc. and view the resulting characteristics on screen. With a knowledge of the appropriate fault levels (calculated elsewhere) the user then checks the on-screen display to the discrimination between primary and backup devices for the fault current and determines if it is adequate. If inadequate, the user either enters new settings to adjust the discrimination time or, in some cases, can "drag" a characteristic curve to a new position to achieve the required discrimination and the program reports the new setting reflecting the new manually- adjusted position of the curve. Some also include fault calculation capabilities.

2. Protection coordination programs

This software is able to suggest settings/ratings for devices to achieve the required coordination. Some, have extensive libraries of devices they can coordinate, including devices with quite complex characteristics and also support the assessment of potential damage due to fault currents to cables and other equipment. However , the user generally has to enter as part of the data the load and fault currents on which coordination is to be based though some do have the ability to import this data from load-flow and fault analysis results provided certain naming conventions are followed in each program.

3. Integrated fault analysis and protection coordination programs

As described in this paper, fully integrated software packages combines full fault calculation analysis capabilities with the ability to suggest settings/ratings for the coordination of protective devices.

4. Protection design and management systems

This type of system consists of integrated modules providing most of the facilities a protection engineer needs to design and coordinate protection systems - including features such as coordinating over-current <u>and</u> distance protection, providing contingency analysis and event stepped simulation of protection operation, full equipment and records database, producing setting sheets and test schedules, etc.

6.2 Future developments

Future developments that can be expected in this type of software include a move to more fully integrated fault analysis and coordination systems and increased system capabilities. This will undoubtedly also include the porting of mainframe and engineering workstation based software packages to the personal computer to take advantage of the lower costs of both hardware and software development. This is certain to include versions to operate in user-friendly graphical environments.

Another emerging trend is to provide support for much more complex and compound characteristic curves as applicable to modern electronic and micro-processor based protection devices.

In the case of *RELCORD*, the present DOS version of the program can handle power systems with up to 300 nodes, 450 feeders/transformers, 300 devices and up to 200 device types. A new version (due for release around the time of the conference) will allow even larger systems to be analysed, possibly up to 1000 nodes or more, and include a number of new features. It is a 32 bit Microsoft[1]

RELCORD- Relay Coordination V5.15c (300 Bus) 06/06/93 16:30
RELAY OPERATING TIMES (Overcurrent Relay)
STUDY TITLE : ESEA Paper Case Study 2
Three phase fault on line Bus-10 [10] to Bus-70 [70] Ckt 1
Distance to Fault from Bus : 50.0 %

Relay Name	...Relay type...	Relay Amps	C.T. Ratio Pri	/ Sec	Tap Setting	Lever Setting	Relay Op.Time
R2	CDG11-1.3	172.23	100.0	1.0	1.00	.410	1.69
R3	CDG11-3.0	315.75	100.0	1.0	1.00	.220	1.26
R4	CDG11-1.3	2074.73	100.0	1.0	1.00	.330	.34
R5	CDG11-3.0	243.37	100.0	1.0	1.00	.100	1.31
R8	CDG11-1.3	172.23	100.0	1.0	1.00	.100	.30
R9	CDG11-1.3	315.75	100.0	1.0	1.00	.100	.20

Press any key to continue

***Figure 7**. Operation Times - Fault at End of Spur*

[1] Registered trademark of Microsoft Corporation, USA.

Windows version of the program that utilises the advanced graphics features available in this environment.

A new power system database integrated into a PC desktop mapping package has also been developed providing a visual schematic/geographic interface that allows the user to maintain all powers system data (impedances, voltages, equipment ratings etc.) in a central database and selectively extract project files for analysis by programs such as *RELCORD.* Results of analyses will also be able to be superimposed onto the system schematic for output to printers or plotters as a record of the analysis.

This representation of the power system in the PC desktop mapping system also provides a basis for a number of applications benefiting from geographical organisation of data and viewing of data - such as the recording and retrieval of power line defects/maintenance, visually presenting the origin of trouble-calls at times of power outages, etc.

7. CONCLUSION

The potential for improving productivity of staff engaged in the design and management of protection systems, especially for coordinating the settings of overcurrent type protective devices is great. And highly skilled engineering time can be freed up for other activities as a result.

The implementation of the program on personal computers enables the operating personnel in distribution and industrial power systems to carry out device coordination studies on their own desk.

The use of this type of software does not take away the role of experienced protection staff in designing and managing protection systems. Indeed their skills remain essential for assessing the results of the such software-assisted coordination studies and making judgements about how those results may be utilised in arriving at final protection settings. However, what the software can ... and does ... do, is relieve them of much tedious repetitious work to be able to focus their skills on those areas where the greatest benefit will be realised.

As well this software can be used as an effective training tool for both protection and operating staff.

A well managed transfer to computer aided protection design can also have extremely short pay-back periods. One or two projects alone can effect sufficient savings to cover the full cost of a software package - particularly software that has a high performance/price ratio.

The Australian developed *RELCORD* program is now in use in a number of electricity supply authorities and industrial establishments in Australia and overseas. It is also used at a number of educational institutions and has been used at Power System Study Workshops.

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9. ACKNOWLEDGEMENT

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[2] New Zealand distributor of DataShare Power Engineering Software's programs