Protection Over current Curve plotter with Fault locator application

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Abstract: The development of a software application to plot protection coordination curves and provide a distance to fault locator is presented in this paper. The purpose of the application is to aid fault location in power systems. Incorrect tripping of protection relay and fault location on power lines have a significant impact on power system performance. Often protection engineers and technicians need to verify grading of protection relays and to locate faults on power lines. The application developed will allow drawing of protection relay curves to observe coordination of relays. It also has a fault locator for non-homogenous medium voltage networks in distribution which estimates distance to fault given the network topology and measured fault current. The application was developed on Microsoft Excel® using the Visual Basic programming language. This will allow the application to be run on any device supporting Excel, originally planned to run on a smart phone, thus making the software easily accessible. The application allows up to four relay curves to be drawn with a variety of curve types to choose from. The fault locator allows up to four conductor types to be used in the network topology to accurately model the fault path. The fault locator was tested with data obtained from two medium voltage overhead lines and gave satisfactory results.

Keywords: Protection, over current, curve plotter, fault locator, Excel, Visual Basic, medium voltage

1. INTRODUCTION

Any power system is susceptible to short circuit faults that may be induced by natural elements such as lightning or maintenance issues, even human error. These short circuit currents cause thermal stresses which may damage power system equipment. Circuit breakers and their associated relays are deployed across the power system to detect and isolate sections with faults. In a distribution network the isolated section may contain a significantly large customer base which makes it paramount that the fault is located, remedied and supply restored. At times incorrect coordination of protection relays can delay the fault location process, which is undesirable. Distribution networks have long power lines which need to be patrolled when searching for a permanent fault. These long drives also delay the restoration of supply and are also costly.

A software application is proposed to be used on distribution power lines by protection engineers and technicians to plot relay protection curves to aid in coordination (grading). By plotting these curves an assessment can be made as to the correct coordination and allow quick corrections to be made where needed.
The application will also be able to afford the user to model a basic distribution power line allowing the selection of up to 4 different conductor types. Using the relay measured fault current the distance to fault will be provided by the application.

2. AIM OF THE PROJECT

The aim of this project in to develop a software application for drawing of protection relay curves to be used in relay coordination assessment and implementation as well as to provide distance to fault functionality for distribution non-homogeneous medium voltage power lines.

3. BACKGROUND TO THE PROBLEM

3.1 Distribution Power Line Topology

A typical distribution power line is supplied from a single bus bar from the source substation. Figure 1 shows a radial type of network. A variety of conductors can be used on a single line which is the reason why distribution networks are labelled as non-homogenous. pole mounted breaker (PMB) which are a combination of a breaker and relay are installed strategically on the back bone (along conductor 1, 2 and 4) and on major T-off's (conductor 3 and 5) to ensure that only a small portion of the network is removed if a short circuit is detected.

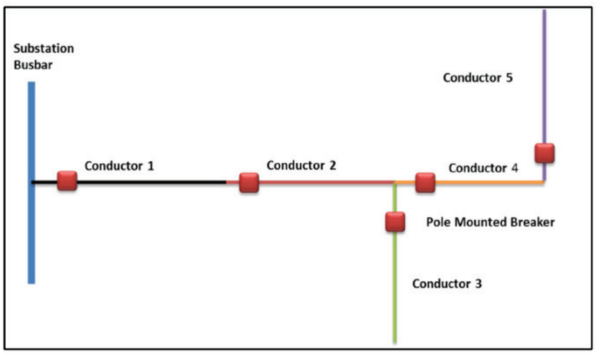


Figure 1: Distribution Power line Topology

3.2 Relay Coordination

Relay coordination is important to ensure that only the section of the power system affected by the short circuit is isolated. Relays can be coordinated using time, current magnitude or a combination of both. The Inverse Definite Minimum Time (IDMT) group of curves is used for this purpose as they provide both current and time coordination. The short circuit current is related to the relay operating time (t_{trip}) indicated by Equation 1 where TM is the time multiplier used to coordinate by time, I_T is the starting or pick-up current used to coordinate by current. I_f represent the fault current as an independent variable. The gradient of the IDMT can be varied by changing the parameters as given in Table 1 [1].

$$t_{trip} = \frac{\beta}{\left(\frac{I_T}{I_f}\right)^{\alpha} - 1} \times TM \quad (1)$$

Table 1: IEC IDMT Curves

Relay Characteristic	***IEC 60255***	
	α	**ß**
Standard Inverse	0.02	0.14
Very Inverse	1	13.5
Extremely Inverse	2	80
Long Time Standby Earth Fault	1	120

3.3 Fault Location

Successful fault location in a power system requires good coordination between protection devices coupled with human intervention. Opening of a PMB is the first indication of a short circuit or fault and their strategic positioning indicate the possible location of the fault.
Human intervention is then required to patrol the line to locate the fault. This may take a long time as well as long drives due to the complex topology of distribution power lines. Some major T-off on a distribution line may have minor T-off's which do not have PMBs installed. Such T-off's are at times the cause of longer fault location times as they also need to be patrolled. Sectionalisers as well as fault path indicators are sometimes used on the minor T-off's to indicate to the field engineers and technicians were the short circuit flowed [2] [3].

Advanced relays used at the substation incorporate a distance to fault locator that uses the measured current and voltage at the relay point to predict the fault location thus aiding in fault finding. The short coming with these relays is that they do not cater for the non-homogeneous topology of distribution power lines.

4. METHODOLOGY OF THE PROJECT

4.1 Curve Plotter

A software tool was developed in Microsoft Excel® to aid in the protection curve coordination. It allows up to four relays to be coordinated. ANSI/IEEE and IEC IDMT curves as well as the definite time curve are implemented as per Equation 1 and Table 1 respectively. Inputs to be entered by the user to alter the result are the pick-up (I_t) and time multiplier (TM) setting. The other choices are electable.

4.2 Fault Locator

The fault locator function in the application uses a predefined network short circuit versus distance profile to estimate the distance to fault. The basic principle used is ohms law as show in Equation 2. The total impedance in the equation is dependent on the source impedance Zs, conductor characteristics and its length. The impedance thus determines how much short circuit current can flow in the circuit [4].

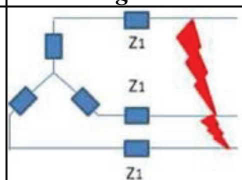
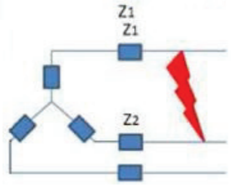
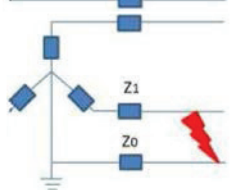
$$V = I_{SC} \times [Z_S + Z(R, X/km \times l)] \quad (2)$$

Re-arranging the equation the distance to fault can be represented as a function of the short circuit current with the conductor kept as constant.

$$l = \frac{V}{[Z(R,X)] \times I_{SC}} - Z_S(km) \quad (3)$$

In a power system sequence impedances of conductors are used to calculate short circuit current based on symmetrical component methods [5]. Table 2 show the equations that are used to calculate the short circuit (SC) current for a 3 Phase, 2-Phase and Single Phase short circuit in the network. Z1, Z2.

Table 2: Sequence impedance calculation of a SC

Fault Type	***Diagram***	***Equation***
Three Phase		$I_{sc} = \frac{U}{\sqrt{3}\lvert Z_1 \rvert}$
Phase-Phase		$I_{sc} = \frac{U}{\lvert Z_1 + Z_2 \rvert} = \frac{U}{\lvert 2Z_1 \rvert}$
Phase-Earth		$I_{sc} = \frac{U}{\sqrt{3}\lvert Z_1 + Z_2 + Z_0 \rvert}$

4.3 Software development in Excel

The software was programmed using the Visual Basic for Applications (VBA) programming language in Microsoft Excel® 2010. VBA was chosen as it provides handling of large data stored in tables and provides in-built functions such as "VLOOKUP" to access data in multi-column multi-row tables. Excel also provides the UserForm functionality to create user interfaces which can be interfaced with the VBA code. The application has three main layers i.e. Data, Application and User Interface. Figure 2 illustrates these layers and the basic functions of each [6].

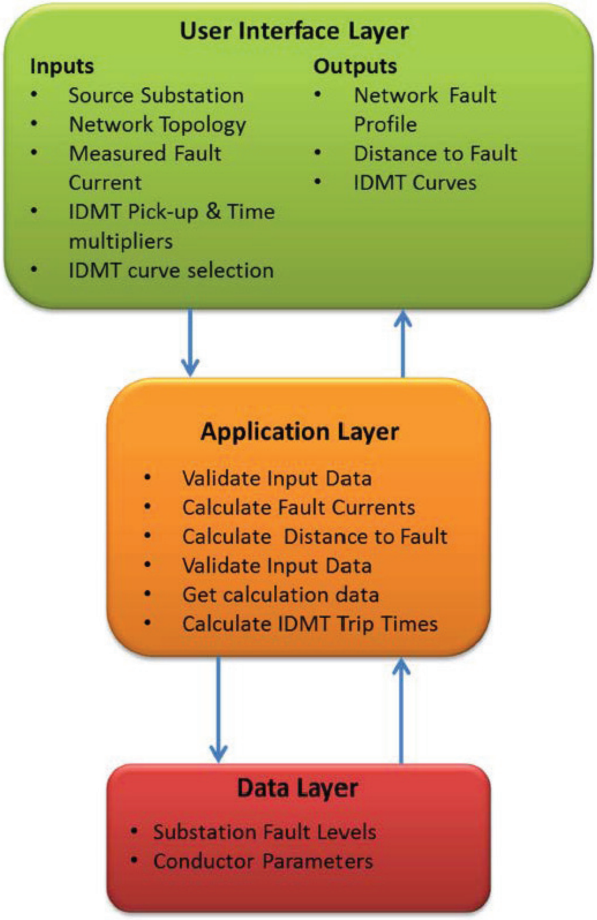


Figure 2: Application design levels

The user Interface allows the user to choose up to four conductor types from a range of conductor types used on distribution lines. The length of each conductor is also required. The user also needs to select the PMB position and the measured fault current for the fault being investigated. The feeder substation 3-phase and single faults are also required as inputs to calculate the source impedance. The application will then draw fault current versus distance curves for 3 phase, phase-phase and single phase faults. From these plots an estimate of the distance to fault is given as an output.

The application then uses this information to plot a fault current versus distance curve for the particular topology selected.

4.4 Data Used

Typical conductor types used on distribution power lines are Hare, Mink, and Fox etc. Measured parameters for these conductors were obtained from Eskom to accurately model the power lines. They were provided in table form with positive (Z1 to Z2) and zero (Z0) sequence impedances per kilometer.

Four different power line topology layouts were also sourced from Eskom to be used for testing. The topology layouts were obtained in two forms. The first is the geographical layout which illustrates the power line distribution as well as conductor types and lengths. These are obtained from the geographical modeling software called Smallworld [7]. The second format was Reni diagrams which are normally used by field staff during fault finding.

The Reni diagram provides details on power line conductors, pole numbers and PMB positions. The Reni diagrams do not have information on conductor lengths, however an assumption is made on span lengths between consecutive line poles of 100m. Thus if there are 10 poles from the substation to the point of interest or where the PMB is located one can estimate a total length of 1000m = 1km.

Fault data was sourced in the form of event logs downloaded from a number of PMB on the power lines. An example of event log is shown in Figure 3.

```
2015/03/06 03:48:01.23 PM  Lockout
2015/03/06 03:48:01.17 PM  Prot Trip 4
2015/03/06 03:48:01.17 PM  Phase Prot Trip
2015/03/06 03:48:01.17 PM  Prot Group A Active
2015/03/06 03:48:00.40 PM  Pickup
2015/03/06 03:47:58.68 PM  Automatic Reclose
2015/03/06 03:47:28.74 PM  E Max 128 Amp
2015/03/06 03:47:28.74 PM  C Max 447 Amp
2015/03/06 03:47:28.74 PM  B Max 425 Amp
2015/03/06 03:47:28.68 PM  Prot Trip 3
2015/03/06 03:47:28.68 PM  Earth Prot Trip
2015/03/06 03:47:28.68 PM  Prot Group A Active
2015/03/06 03:47:27.78 PM  Pickup
2015/03/06 03:47:25.77 PM  Automatic Reclose
2015/03/06 03:47:14.92 PM  Load Supply OFF
2015/03/06 03:47:10.88 PM  E Max 137 Amp
2015/03/06 03:47:10.88 PM  C Max 448 Amp
2015/03/06 03:47:10.88 PM  B Max 425 Amp
2015/03/06 03:47:10.77 PM  Prot Trip 2
2015/03/06 03:47:10.77 PM  Earth Prot Trip
2015/03/06 03:47:10.77 PM  Prot Group A Active
2015/03/06 03:47:10.70 PM  Pickup
2015/03/06 03:46:58.23 PM  Load Supply ON
2015/03/06 03:46:54.14 PM  Automatic Reclose
2015/03/06 03:46:53.29 PM  Load Supply OFF
2015/03/06 03:46:49.20 PM  E Max 115 Amp
2015/03/06 03:46:49.20 PM  B Max 558 Amp
2015/03/06 03:46:49.20 PM  A Max 532 Amp
2015/03/06 03:46:49.14 PM  Prot Trip 1
2015/03/06 03:46:49.14 PM  Earth Prot Trip
```

Figure 3: PMB event log example

The PMB, Nulec CAPM4 series, was used for the project and is manufactured by Schnieder Electric. Following analysis of the fault log, information about where on the network the fault was found was sourced. This was obtained from the Eskom in a list of Work Orders including detail of the time, date as well as feedback from the field staff that performed the fault finding. PMB protection settings were also sourced from the Eskom Protection Coordination & Configuration department. These were used to evaluate and validate the protection curve plotter function.

5. EVALUATION OF THE APPLICATION

The application's use is best illustrated using examples. Case studies will be presented to cover usage of the curve plotter as well as the fault locator functions.

5.1 Curve Plotter Case Study

A technician is on site to do maintenance on 4 PMB's connected in series as shown in Figure 4.

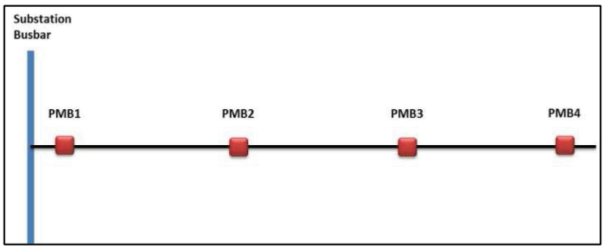


Figure 4: Curve Plotter Example network

Part of the maintenance schedule is to check that the settings on the PMB are the same as that on the database in the office. On inspection of the settings sheets for all the breakers it becomes clear that the time settings may not be coordinating as indicated in Table 3.

Table 3: Curve Plotter Example Relay Settings

PMB	*Pick-Up Setting*	*Time Setting*	*Curve Type*	*Fault level*
1	200A	0.3	IEC NI	3000
2	150A	**0.25**	IEC NI	2600
3	100A	**0.23**	IEC NI	1500
4	70A	**0.25**	IEC NI	1000

The technician then inputs the settings into the curve plotter application which was loaded onto a portable device to be used in the field to confirm the suspicion. The result is indicated by a screen capture in Figure 5 and enlarged plots in Figure 6.

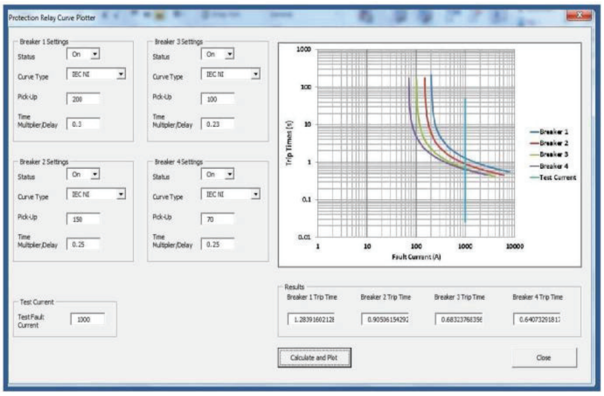


Figure 5: Screen capture of Curve plotter user interface

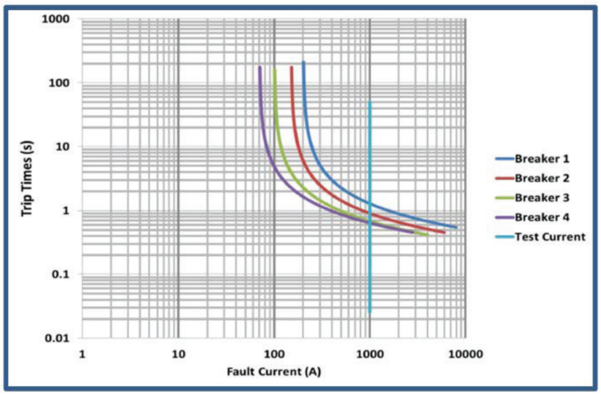


Figure 6: Poorly coordinated relay curves

To correct the possible mistake and investigate a more proper setting the technician then changes PMB3's time setting to 0.2 and PMB4 to 0.15. The result is as shown in Figure 7.

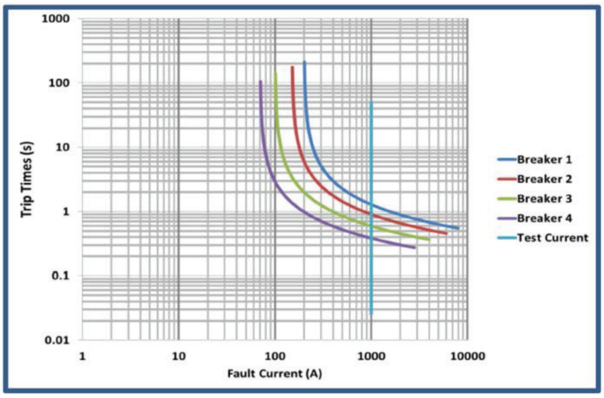


Figure 7: Coordinated relay curves

5.2 Fault Locator Case Study

This case study is based on an actual fault that occurred on the Reddersburg Munic-Sydenham line denoted RESY.

The network layouts are shown in Figure 8. The PMB at RESY351 tripped at 4:15 PM on 22/01/2014, see event log, Figure 9. The measured current was about 270A on each phase.

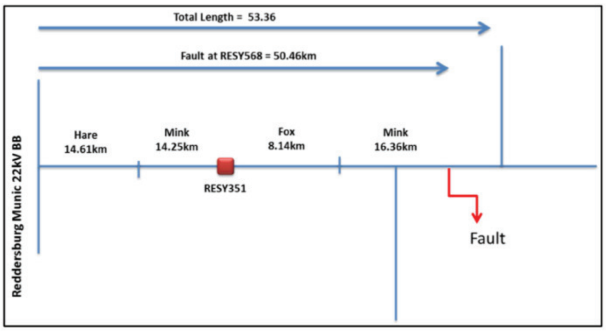


Figure 8: Reddersburg Munic – Sydenham line topology

```
2014/01/22 04:15:18.88 PM  E Max 37 Amp
2014/01/22 04:15:18.88 PM  C Max 266 Amp
2014/01/22 04:15:18.88 PM  B Max 275 Amp
2014/01/22 04:15:18.88 PM  A Max 257 Amp
2014/01/22 04:15:18.82 PM  Prot Trip 1
```

Figure 9: RESY351 Trip Event Log

Using the fault locator tool the conductor types and lengths were entered into the application. The substation was selected from a list and the measured fault current entered. The screen capture is shown in Figure 10.

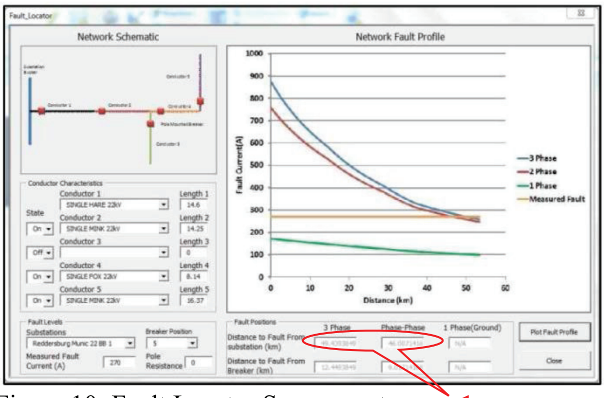


Figure 10: Fault Locator Screen capture

The fault locator estimates that the fault is either a 3 phase fault at 49.43km from the substation bus bar or a Phase-Phase fault at 46km (point 1, Figure 10).

Looking at the event log one can see that all three phases produced about the same fault current meaning the fault must have been a 3 phase fault at 49.43km and 12.44km from the RESY351 PMB that tripped.

Work order data shows that the fault was found RESY568 which is 50.46km from the substation, Figure 8. The fault was caused by a failed pole mounted transformer. This example illustrates how the fault locator can be used to aid in fault finding. Similar tests were done with earth faults and the results were proven to be satisfactory.

6. CONCLUSIONS

An application tool has been developed to aid in fault finding on distribution power lines which could be used remotely. The software was developed in Microsoft Excel® VBA. A protection curve plotter was implemented to help in coordinating protection relays. An example was given of how this can be done and to evaluate the applications operation. A fault locator component was also implemented with and tested with 3 phase and earth fault. The results were satisfactory evaluated and tested.

Although the end product was not implemented on a smart phone as originally planned it proofed the concept to be implemented as a future research project.

7. REFERENCES

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8. ACKNOWLEDGEMENTS

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