AN ACCURATE FAULT LOCATOR
FOR TRANSMISSION LINES

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Abstract - Superior accuracy obtained by a microprocessor based fault locator is presented. Prefault and fault data extracted from the AC currents and potentials are used to compute the distance to the fault. The distance is displayed in percent of the transmission line length. Remote indication and local print out of the fault information are provided. Repair and restoration of the transmission line following a fault is thus facilitated.

INTRODUCTION

Distance relays provide some indication of where a fault occurred on a transmission line by means of which zone of protection operated to clear the fault. They are not designed to pinpoint the location of the fault. With knowledge of the fault location, faster repair and restoration of the transmission line can be facilitated. A fault locator is also a useful tool in evaluating transient faults which otherwise could cause weak spots in the transmission system resulting in future problems or faults.

Fault locators have had limited applications in the U.S. due to high cost, poor reliability and inaccurate results. The described design offers high accuracy at moderate cost, using a microprocessor and proven relay components and concepts.

Pre-fault load currents are stored and continuously updated within the fault locator. These values are then used for compensation in the determination of the fault for a high degree of accuracy. This novel approach is briefly described as well as the operation, hardware, and applications.

NEED FOR FAULT LOCATORS

Fault locators perform a valuable service regardless of the utility practice in use after a permanent fault. In the case where helicopters or airplanes are used to patrol the line, it may not be possible to fly due to weather conditions, thus causing a longer delay in restoration of the line. Even under good weather conditions, the problem may have disappeared by the time the line is patrolled. For example, tree growth could reduce the clearances under heavy loading of a line, resulting in a flashover. By the time the patrol arrives, the conductors have cooled and increased the clearance to the tree. Thus, the problem area is not obvious or found.

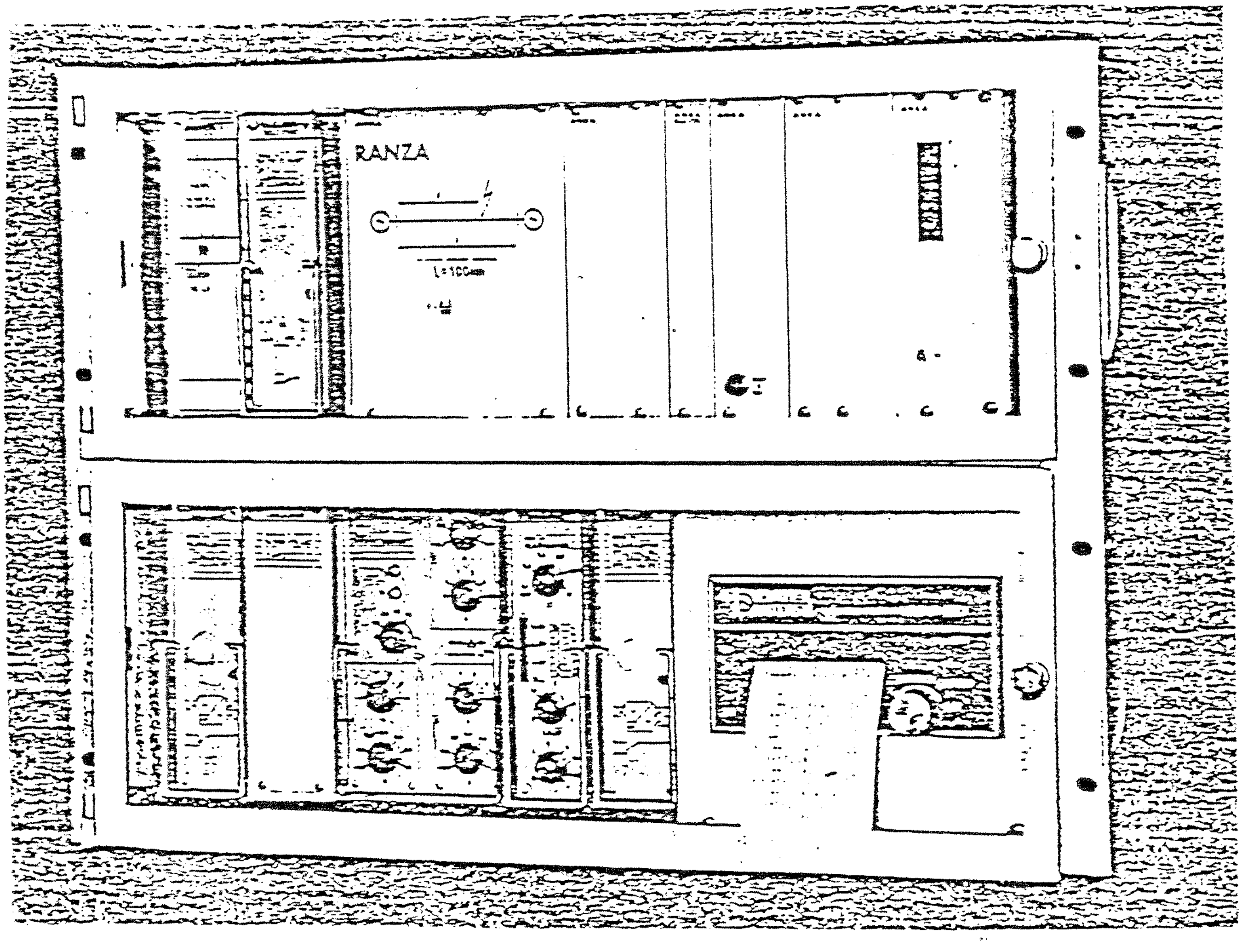
Fault locators can play an important role where foot patrols are used, particularly on long lines or in rough terrain. Locators can also help where maintenance jurisdiction is divided between different companies or divisions within a company.

Fault locators are valuable even where the line has been restored after a fault. There are many examples of such cases: cranes swinging into the line, brushfires, damaged insulators, and vandalism, to name a few. One such case reported was as follows. A phase-to-phase fault occurred on one line almost every day, Monday through Friday, at about 4:30 PM. The faults did not always involve the same phases. Patrolling the line proved unsuccessful in determining the cause. The line would trip out and reclose every time. It was finally decided to station personnel along the line to try to determine the cause of these trips. A country school would let out at 4:15 PM each day. As the children walked home, they passed a place where a drainage tile went under the road. One of the boys would then proceed to take out a piece of pipe from the tile and throw it into the transmission line thus causing a phase-to-phase fault. After the pipe fell to the ground, he would again place it in the drainage tile removing all evidence. A fault locator would have been a very useful tool in pinpointing the location of these faults, thereby reducing the manpower required to determine the cause of the faults. Weak spots that are not obvious may also be found because a more thorough inspection can be focused on the limited area defined by the fault locator.

HARDWARE

Figure 1 shows the "RANZA" package suitable for 19" rack mounting. The bottom half of the assembly consists of optional items: the printer and the fault-type selection underimpedance and ground overcurrent units. The latter is used when phase selection outputs are not available from existing line protection relays. Alternatively, the basic 7" x 19" assembly can be provided in a case for flush or semi-flush mounting.

The three phase currents and potentials, as well as other inputs, enter the fault locator through the test switch, a standard feature in protective relays. The switch provides for isolation of the equipment from the instrument transformers and for the injection of test quantities using the same test plug which is used for protective relays.



The unit is powered from the station battery via the dc/dc converter. The "transformer" unit provides galvanic isolation from the instrument transformers, as well as transforming the signals to a level suitable to the electronics. A screen between the windings minimizes common-mode surge coupling. The secondaries feed a "shunt" unit mounted on the back, consisting of resistors and surge voltage limiters. The signals then feed into the mother board for the electronics.

The "input" unit contains reed relays which provide galvanic isolation for the on-off indications from the phase selectors (three phase and one ground) and a breaker trip from the line protection.

The "measuring" unit is the heart of the locator system, consisting of:

- R-C low-pass filters for signal conditioning using a 500 Hz cutoff frequency.
- Multiplexer, hold circuits and A/D converter.
- Microprocessor
- Memory for measured data and microprocessor operating instructions.
- Input and output drivers.

The "output" unit contains a two position LED display to indicate the distance to the fault in percent — the top position has a weight of ten and the bottom position a weight of one, accommodating a range of 0 - 99%. In the test mode the display is used for data or error-code outputs. In addition, the output unit contains:

- Reed relays to alarm for microprocessor failure.
- 20 mA current output for the printer.
- Reed relay for telemetering start.
- Reed relays for telemetering (binary coded outputs of two LED units).

Loss of auxiliary voltage output signal is available in the dc/dc converter..

The "setting" unit contains five thumbwheel switches and a pushbutton for the inputting settings for the specific application into the memory. The pushbutton, which is accessible by simply opening the windowed door, initiates the functional tests and resets the LED display.

The optional bottom assembly contains the printer fed from the station battery via a dedicated dc/dc converter. Also shown in Figure 1 are the optional phase underimpedance and ground overcurrent units for the phase selection with their dedicated dc/dc converter.

SYSTEM OPERATION

Figure 2 shows the main elements of the hardware. The digital inputs consist of the "start" signal from the line-protection-relay breaker-trip output and phases A, B, C and ground phase selection from the line protection or from the optional integral phase underimpedance and ground overcurrent units. The "start" input initiates a distance-to-fault computation.

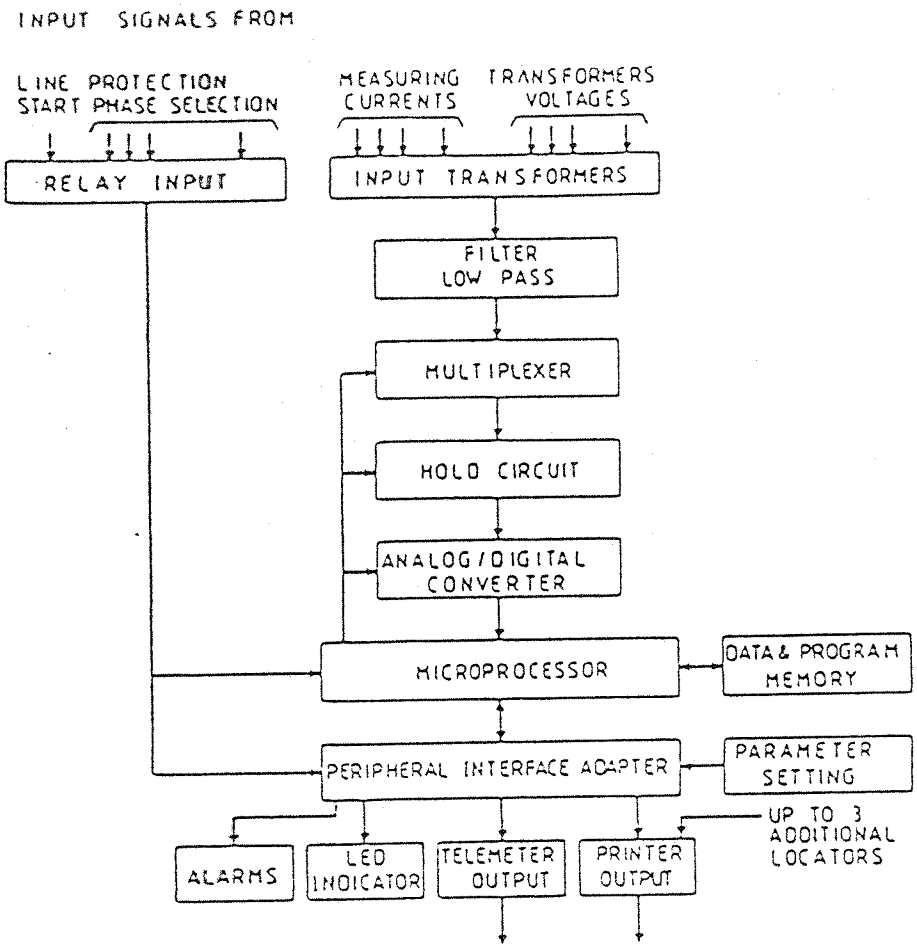


Figure 2: Hardware configuration.

The analog signals feed through input transformers to low pass filters. The filter outputs are switched in sequence by the multiplexer and feed into the hold circuit in preparation for conversion to a digital value proportional to the instantaneous value of the ac wave. Both the digitized signals and the relay input status are stored in a 6 cycle circular file. Continual updating occurs until the "start" freezes the data for the duration of the distance-to-fault computation. Once the percent distance is displayed, the locator returns to its normal mode, with continual data recording. The percent display continues until the next "start" input from the line protective relays or the optional phase underimpedance and ground overcurrent units or until reset by the pushbutton, whichever occurs first. After a manual reset of the LED display, the value remains in memory until the next "start" input or loss of dc power. This data can be accessed and re-displayed by four pushbutton operations within a 5 second interval.

The program and settings are stored in memory. The microprocessor will automatically restart after a dc power loss and restoration.

When the microprocessor senses a "start" input, the six cycles of data are frozen. Then, selected samples are processed by using the real and imaginary quantities. No new data enters the six cycle circular file until the computations are complete. Any subsequent "start" input will be ignored during the computation interval.

With a printer, the percent distance to the fault is printed in one of three formats, selected by setting parameter number 9. These formats are designated A, B, and C. Figure 3 shows an example of formats A and B.

Format B prints the computed RMS values of the fundamental component of the ac signals in polar form, for both pre-fault and fault quantities. Format C is identical except the values are printed in rectangular form. Current values are based on a 1 amp CT rating. For a 5 amp locator the transformer unit is changed to produce the same secondary voltage levels as the 1 amp locator. Thus the printed current values must be multiplied by five to determine the actual 5 amp CT secondary currents.

```
Line number 1


Relative distance to                         A
fault p = 75%

Phase = RN, Loop = RN


IR   =  AMPL.  =  002,213 A
        ARG.   =  028,4 DEG.
IS   =  AMPL.  =  000,292 A
        ARG.   =  308,7 DEG.
IT   =  AMPL.  =  000,831 A
        ARG.   =  212,0 DEG.
IR0  =  AMPL.  =  000,519 A
        ARG.   =  103,1 DEG.
IS0  =  AMPL.  =  000,514 A      Pre-fault        B
        ARG.   =  343,3 DEG.
IT0  =  AMPL.  =  000,524 A
        ARG.   =  223,1 DEG.
IN   =  AMPL.  =  001,475 A
        ARG.   =  015,1 DEG.
UR   =  AMPL.  =  052,157 V
        ARG.   =  093,0 DEG.
US   =  AMPL.  =  062,611 V
        ARG.   =  332,9 DEG.
UT   =  AMPL.  =  063,192 V
        ARG.   =  210,5 DEG.
UR0  =  AMPL.  =  063,510 V
        ARG.   =  092,0 DEG.
US0  =  AMPL.  =  063,672 V      Pre-fault
        ARG.   =  331,7 DEG.
UT0  =  AMPL.  =  063,774 V
        ARG.   =  211,9 DEG.
```

The printer will accept four fault locator inputs. The program checks the printer loop for activity. If none, it takes control of the printer until its output task is completed. When the printer loop is active with another fault locator, it waits until the activity is completed before it takes control of the printer.

The telemetering output consists of eight reed relays in two sets of binary coded outputs, mirroring the tens and one digit LED display. The data output to the printer is not telemetered.

CONTINUOUS MONITORING

The microprocessor continuously executes a monitoring routine. If the microprocessor fails to periodically output an "all's well" signal, a peripheral circuit operates an alarm relay with one dry contact output.

TESTING

Overall calibration testing requires the injection of ac signals from a test source, just as is done for protective relays by opening the cover of the test switch and inserting an 18 position test plug. With the test plug in place, the ac currents from the CT's are automatically bypassed from the locator and isolated along with the ac potentials. The dc source is left intact to maintain normal power for the electronics. Test quantities can then be injected to the locator through the test plug without disturbing other relays in the same circuits.

Table I lists the operations that can be initiated by the pushbutton with the cover of the setting unit in place and the internal thumbwheels in the 00000 position. One of four operations can be selectively initiated depending on the number of pushbutton closures within a five second interval. One pushbutton operation initiates all four functional tests sequentially on the various hardware. If all tests are successful, no information is displayed. If a functional test fails, an error code appears on the LED and the sequence halts until the pushbutton is again operated to continue the sequence.

Functional test No. 1 checks the calibration of the electronics by reading the value of a 5 V dc reference signal applied to the A/D converter. If within established tolerances the test is successful. Test No. 2 checks for a 20 mA flow in the printer loop. Functional test No. 3 adds the values stored in all the EPROM addresses and checks it against a previously determined value. If they don't match, an error code is displayed on the LED. Functional test No. 4 stores a value in each RWM memory location in turn and then loads it into the CPU and checks the loaded value.

Multiple pushbutton operations within a 5 second span initiate other tests, per Table I. Two pushes will generate a freeze and dump of the six cycle circular file of analog signals. RMS values are calculated and printed in polar form. Three pushes initiates a setting parameter dump. The values are displayed sequentially on the LED's. The 10's position shows the code (1 to 9) of the parameter being displayed; the digits of that parameter are displayed sequentially. The values are also printed if a printer is used. Table III lists these setting parameters. Four pushes displays the percent distance to the fault of the last computation; this recovers the reading should the pushbutton be operated inadvertently before recording the result. (Each time the pushbutton is activated, the LED display is reset.)

For troubleshooting the tests in Table II can be initiated by a single operation of the pushbutton, but with the internal thumbwheel switches set at various values as indicated. As with Operation A of Table I, there will be no LED display unless an error occurs. Only Test No. 2 provides a printer output — a complete character set.

SETTINGS

Table III shows the parameters to be set by the user. See "Definition of Terms". Parameters 1 to 4 are the line constants, while 5 to 8 are the source constants. The source impedances will change with system conditions, so a representative value is selected. Variations in source impedance have only a secondary effect on the results, depending primarily on the magnitude of fault resistance.

The parameter is selected with the top thumbwheel and the value placed on the other four switches (0 to 999.9 ohms). A pushbutton operation initiates memory burn-in.

The digits of parameter #9 are determined with four different items. The "type of phase selection" determines which phase quantities are processed for multi-phase-to-ground faults. The "normal" selection directs the program to process a double-line-to-ground fault as a phase-phase fault. The "cyclic" or "acyclic" choices are available to coordinate RANZA with relays protecting resonance grounded systems. For cross-country single-phase-to-ground faults this allows RANZA to measure on the same loop as the relay which provides the start signal.

The CT polarity digit may be changed from 1 to 2 if the CT wiring is reversed from the intended polarity or if the locator is used on a double bus where the direction is changed due to switching on the power system. The third digit determines the printer format. The fourth digit allows a line number designation from 0 to 9 to be assigned to each fault locator.

APPLICATION CONSIDERATIONS

The "RANZA" fault locator is suitable for use with lines having secondary impedances in the range of 0 to 200 ohms based on 5 amp CT's. It is available with a 1, 2 or 5 amp current rating, withstanding three times rated current continuously, thus allowing a 2 amp rating to be used on a 5 amp CT secondary, thereby giving a greater sensitivity.

It is designed for use with the relay instrument transformers and introduces a burden of 1 VA per phase at rated current and voltage.

The "RANZA" is designed and tested in the same manner as all protective relays. The operating temperature range is 0 to 55°C. It requires 1.5 cycles of fault duration for an accurate measurement. It is not necessary to apply a locator at each line terminal. No external clock or communication link is required. Four locators can share one optional printer. The percent distance to the fault can be remotely logged using the built-in telemetering outputs from the locator.

SUMMARY

- The fault locator displays the percent distance to the fault.
- Calculations use mainly the prefault current, but representative source impedance values can be set into the memory to give a second order improvement in calculation accuracy.
- The microprocessor based system is designed, built and tested to protective-relaying standards, including surge withstand requirements.
- It is suitable for use with relay instrument transformers, introducing negligible burden.
- Extensive software filtering minimizes the effects of power system and instrument transformer transients.
- The microprocessor monitors itself and built-in functional test facilities can pinpoint a system failure.
- The locator can function with either the line relay phase selectors or with the optional built-in selector.
- Only one end of a line needs to be equipped with a locator.
- No external clock or communication link is required.
- Telemetering output is built into the basic unit for remote percent distance to fault indication.
- An optional printer can handle up to four locators, providing fault data and percent distance to fault indication.

TABLE I: PUSHBUTTON INITIATED OPERATIONS

(Setting Unit Cover On — Internal Thumbwheel Switches at 00000)

Operation		No. Of Pushbutton Operations (Note 1)	Output	
			Printer	LED Display
A)	Functional Tests:	1	No	Yes (Note 2)
	1. Analog calibration (dc reference input)			EC
	2. Printer loop			EC
	3. Read-only memory			EC
	4. Read/write memory			EC
B)	Analog Readings (U & I)	2	Yes	No
C)	Setting Parameter Dump	3	Yes	Yes (Note 3)
D)	Distance to Fault (Last Result)	4	No	Yes

Notes:

1. Pushbutton operations within 5s interval.
2. Displays a "1" during sequence, unless an error occurs.
3. Automatic sequencing, one digit at a time.

EC= Two-digit code, if error.

TABLE II: PUSHBUTTON INITIATED TROUBLE-SHOOTING TESTS

(Setting Unit Cover Off — Various Thumbwheel Settings;

One Pushbutton Operation)

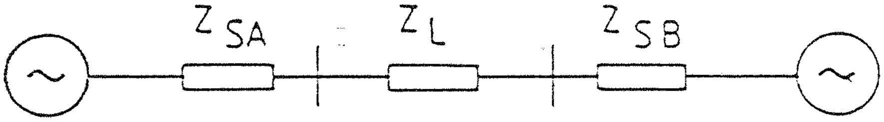
	Test	Thumb-Wheel Positions	Output	
			Printer	LED Display
1.	Analog calibration	00001	No	EC
2.	Printer	00002	Note 1	EC
3.	Read-only memory (sum check)	00003	No	EC
4.	Read/write memory (store/read)	00004	No	EC

Notes:

1. Character set printout.
EC= Two-digit error code, if error.

TABLE III: SETTING & PROGRAMMING PARAMETERS

1. R_{1L}
2. X_{1L}
3. R_{0L}
4. X_{0L}
5. R_{1SA}
6. X_{1SA}
7. R_{1SB}
8. X_{1SB}
9. - Type of phase selection (Normal, cyclic, acyclic)
   - CT polarity
   - Printout (A,B,C)
   - Line number



DEFINITION OF TERMS

R_{1L}, R_{0L} = Positive- and zero-sequence line resistance.

R_{1SA}, R_{1SB} = Positive-sequence source resistance at station A and B respectively.

X_{1L}, X_{0L} = Positive- and zero-sequence line reactance.

X_{1SA}, X_{1SB} = Positive-sequence source reactance at station A and B respectively.