

Numerical Quadrilateral Distance Relay

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Abstract: *The paper presents a new technique for implementation of numerical quadrilateral distance relay. The characteristic of the numerical quadrilateral distance relay is realized by measuring the instantaneous values of the voltage and current based on sampling principle. For this purpose an Advantech data acquisition device is used. The system voltage and current is fed to this device from PT and CT respectively. This device samples the input signals and feed it to the computer. Software in Visual Basic is used to program this device as well as to calculate the resistance & reactance from the measured values of voltage and current. The calculated values are compared with a predetermined set of conditions. These conditions are set according to the quadrilateral distance relay characteristic. Finally, depending on the compared results, trip signal will be generated by software for tripping the circuit breaker.*

Keywords: Line protection, Numerical protection, Quadrilateral distance characteristic

1. Introduction

Electric power system requires protection at generation, transmission as well as distribution level. With advances in technology, protective relays have progressed from electromechanical, to solid state and to numerical relays. The increased growth of power systems both in size and complexity has brought about the need for fast and reliable relays to protect major equipment and to maintain system stability. With the development of economical, powerful and sophisticated microprocessors, there is a growing interest in developing microprocessor-based protective relays (also known as numerical), which are more flexible because of being programmable and are superior to conventional electromagnetic and static relays. The main features which have encouraged the design and development of microprocessor-based protective relays are their economy, compactness, reliability, flexibility and improved performance over conventional relays.

At the transmission level distance relays are preferred to over current relays because they are not nearly so much affected by changes in short circuit current magnitude as over current relays are, and hence are much less affected by changes in generating capacity and in system configuration. This is because distance relays achieve selectivity on the basis of impedance rather than current

The rapid growth of power systems owing to increasing demand, as well as interconnections, has resulted in E.H.V. lines being used over longer distances to deliver the bulk power. Such long and heavily loaded lines demand that greater attention be paid to the problems arising out of the encroachment of the loci of maximum load and power swings into the distance-relay characteristic. Attempts to overcome these problems have resulted in the quadrilateral characteristic, which fits the fault characteristic of the transmission line fairly well.

In all the research and analysis done on the quadrilateral distance relay till date, there are some possible errors that mostly occur during the acquisition i.e. the while reading the voltage and current signals in the computer/microprocessor

from the outside world. Because in most of the above mentioned research work the researcher have used electronics based hardware to read data from the PT and CT. Such kind of hardware introduces error in the calculated value of impedance if the input signal contain transient or harmonic component.

This paper presents a new way of implantation and testing of quadrilateral distance relay characteristics using Advantech data acquisition device USB4711/A. that reduces the possibility of error, This is because of high level of accuracy of data conversion (analog to digital and vice versa) and high speed data sampling capability of this device

2. Distance Relay for line protection

In the transmission line protection, the use of distance relays has found to be the most feasible and effective as compared to the other type of protection such as current actuated relay (over current relay). If over current relays are used for the protection of transmission line, the mal-operation occurs. This is due to the fact that they principally depend on only one actuating quantity i.e. current which many a times affected by arc resistance, source impedance, types of faults etc. On the other hand, the distance relay takes care of all of these factors and gives better performance. That is why the distance relays are preferred for the protection of transmission line over other types of relays. But the performance of these distance relays is also affected by the factor like power swing and arc resistance. This problem can be solved by designing a relay which has minimum area on R-X plane so that it is least affected by power swing and takes care of arc resistance also [3].

Amongst all types of distance relays available today, the quadrilateral relay is one which has least area on R-X plane and is not affected by the arc resistance. Hence, the proposed project aims at implementation of numerical quadrilateral distance relay.

The numerical relays have some attractive advantages over conventional methods such as:

1. It require minimum hardware, hence it is compact, economical, & reliable.
2. Characteristic does not change with time and temperature.
3. It is programmable hence flexible.
4. It offers a great flexibility in terms of onsite changes in the characteristic.

3. Quadrilateral distance relay characteristic

The distance relay operates, when the impedance seen by the relay is less than the set value, i.e.

$$Z_R < Z_{set}$$

Where

Z_R = impedance seen by the relay = $R + jX$

Z_{set} = impedance of line of line to be protected.

R and X are respectively the resistance and reactance measured by the relay.

The quadrilateral distance relay characteristic is consisting of four straight lines as shown in figure 1.

The positive torque region is the region covered by all the four line i.e. quadrilateral ABCD. If the impedance seen by the relay is inside the operating region, then relay trips.

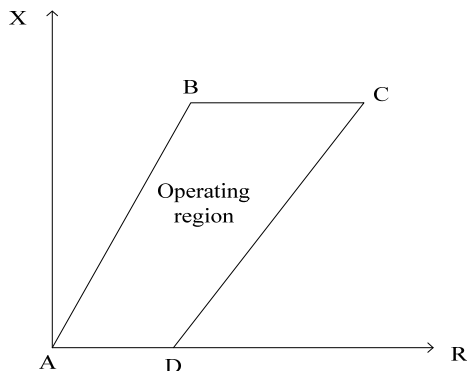


Figure 1. Quadrilateral distance relay characteristic

Each of these lines can be described by an equation given by:

- Line AB: $X = m_1 * R$ (1)
- Line BC: $X = \text{constant}$ (2)
- Line CD: $X = m_2 * R + C$ (3)
- Line DA: $X = 0$ (4)

Where m_1 is the slope of the line AB, m_2 is the slope of the line CD and C is the constant [5].

4. Voltage & Current Signal processing

In order to develop quadrilateral distance relay characteristic by numerical technique voltage and current signal are needed in digital form. In this paper the voltage and current signals are fed to the computer via data acquisition device USB4711/A as shown in following figure 2

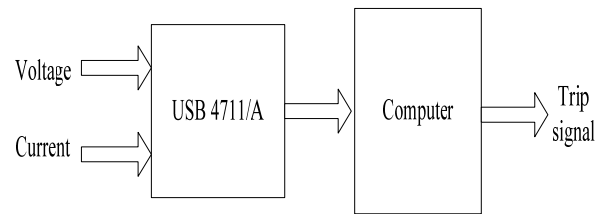


Figure 2. Block diagram of hardware

Here both voltage signal (V) and current signal (I) are taken from potential transformer (PT) and current transformer (CT) respectively and fed to USB4711/A device. In order to reduce level of these signals to the acceptable level of USB4711/A device a small hardware as shown in figure 3 is needed. In this hardware voltage and current signals are processed as follows:

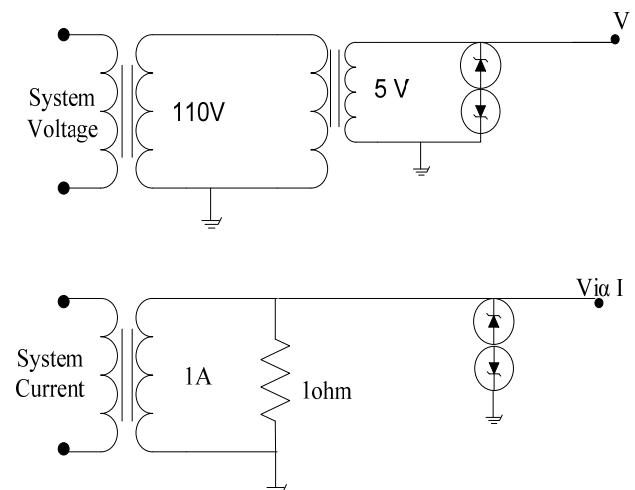


Figure 3: Circuit for signal input

Voltage Signal:

Since the input voltage range of this device is +/- 10 volts, after getting the voltage at the output terminal of potential transformer at 110 volt level it is again stepped down to a level of 5 volt using another potential transformer, to make the level of the voltage signal to match with the input rating (+/- 10 V) of the data acquisition device.

Current Signal:

Normally, the secondary rating of the Current transformer is 1 A or 5 A. In proposed project CT with a secondary rating of 1Amp will be used. Since USB 4711/A can read only voltage signal, a small resistance (1 ohm) is connected across the secondary of the current transformer and the voltage across this resistance is fed to analog input channel of USB 4711/A.

To read/scan both of these input signals from the input channel of USB4711/A a software is developed. This software continuously scans both the channels and further processes them to estimate the values of resistance and reactance. All this work is done by the software in synchronism with the time.

5. USB4711/A

The Advantech USB-4711 is a powerful data acquisition (DAS) module for the USB port. It features a unique circuit design and complete functions for data acquisition and control. As per the requirement of the project this module is very much helpful because of its ability to acquire the data at high speed at the same time it has very good accuracy as far as analog to digital conversion is concerned. This module has some important features [6] which are:

- 16 single-ended analog input channels
- 12-bit resolution A/D converter, with up to 100 kS/s sampling rate
- 8 digital input & 8 digital output channels (TTL Level)
- 2 analog output channels
- 16-bit programmable counter/timer x 1
- Programmable gain for each analog input channel
- Automatic channel/gain scanning
- On-board 1K samples FIFO buffer for AI channels
- No need for external power
- Device status LED indicator
- Removable on-module wiring terminal
- Supports high-speed USB 2.0
- Auto calibration function

The specifications of this device are as follows:

- I/O Connector Type: Removable 10-pin screw terminal
- Dimensions: 132 x 80 x 32mm
- Power Consumption: 360mA @ +5.0V typical; 450mA @ +5.0V max.
- Input Voltage Range: +/- 10volt
- Input Overvoltage: 30 V max.
- Input Impedance: 1GΩ
- Output voltage range: 0-5, 0-10, +/-5, +/-10
- Output Impedance: 0.1Ω max
- Temperature: Operation: 0~60 (32~140)(refer to IEC 68 2-1, 2)Storage: -20~70 (-4~158)
- Relative Humidity: 5~ 95 % RH

6. Software development

The data acquisition module USB4711/A which is used in this project can be programmed in following development tools such as Visual C++, Visual Basic, Delphi, and C++ Builder. Now using any one of this development tools software can be developed which to scan the input voltage and current and generate quadrilateral distance relay characteristic.

The software of the project is developed in visual basic. Relay software is a set of equations whose evaluation and comparison with certain predetermined levels determines the operation of the relay. This software scans two input voltage signals and calculates the value of resistance and reactance based on principle of differential equation [1] of the electrical circuit.

6.1 Program Algorithm

- a) Read input voltage and current channel simultaneously for four successive instants of the same time interval.
- b) Compute the value of resistance(R).
- c) Compute the value of reactance(X).
- d) Check if $X > 0$
- e) Check if $X < R$
- f) Check if $X < m1 * R$
- g) Check if $X > m2R + C$
- h) If conditions from d to g are satisfied then issue trip command otherwise repeat the steps a to h

6.2 Program Flowchart

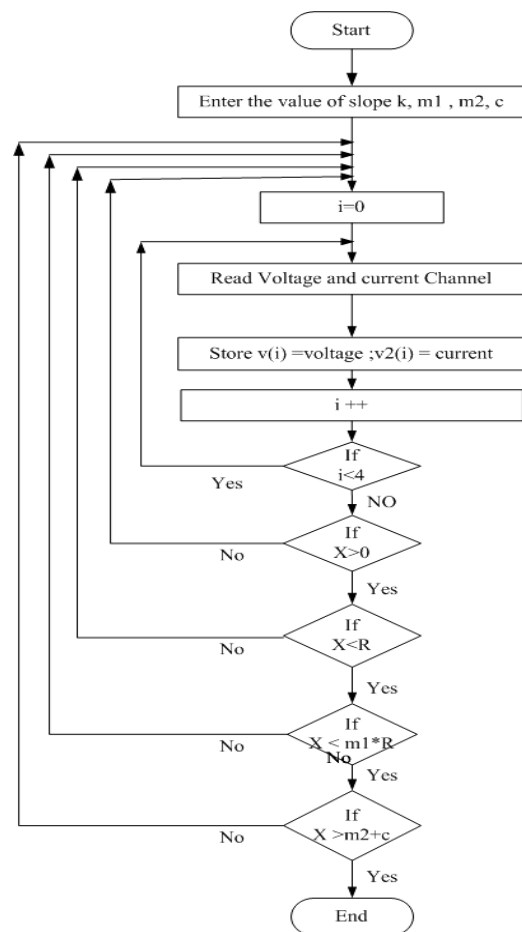


Figure 4. Flowchart

7. Testing of software

To check the developed relay software we have assumed that proposed relay is used for the protection of a transmission line with line impedance of $7.75+j29$ and arc impedance of $2.25ohms$. Under normal operating condition rated voltage and current at the relay terminal are 110 Volt and 5 Amp respectively.

In power system whenever any fault occurs on a transmission line there is change in the magnitude of voltage, current and power factor angle. Accordingly to test software a set of data including system voltage, current and their phase angle corresponding to the fault are assumed. The results for testing are as follows:

DATA 1: Relay voltage =110 V; Relay current= 3 A; Phase angle =75

Parameter	R(Ω)	X(Ω)	Relay Status	Remark
Software result	10.02	36.51	No tripping	Tripping status and result of software are matching with manual calculation.
Result of manual calculation	9.49	35.41	No tripping	

DATA 2: Relay voltage =110 V; Relay current= 5 A; Phase angle = 60

Parameter	R(Ω)	X(Ω)	Relay Status	Remark
Software result	11.07	19.39	tripping	Tripping status and result of software are matching with manual calculation.
Result of manual calculation	11	19.053	tripping	

DATA 3: Relay voltage =50 V; Relay current= 5A; Phase angle = 60

Parameter	R(Ω)	X(Ω)	Relay Status	Remark
Software result	4.98	8.83	tripping	Tripping status and result of software are matching with manual calculation.
Result of manual calculation	5	8.66	tripping	

Note: tripping status of relay in case of manual calculation is determined by plotting a relay characteristic on graph.

8. Conclusion

Extensive software for the implementation of quadrilateral distance relay characteristics developed and verified for various values of voltage and current samples corresponding to fault as well as healthy condition. Final weights obtained after pattern recognition techniques is mentioned here. The software has been verified with manual calculations. It has been found that the level of accuracy of measurement of voltage and current signals with the application of USB4711/A device is much better as far as the requirement of digital protection is concerned.

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