

# Multifunctional Relay Developed in ATP „FOREIGN MODEL“ and C++

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**Abstract:** - This paper presents new approach in the problem of digital relay development. To the improvement of digital relays, an interactive model in the simulation program of power system, e.g., ATP-EMTP, could properly contribute. This model is not available and a code for this model has to be created in ATP. There is an internal programming language MODELS in ATP which allows creation of programs themselves but because of its simplicity it is not sufficient for developing sophisticated models as in object oriented programming languages. This deficit is compensated for by allowing a suitable interconnection between the ATP computing core and external model developed in another programming language. For this reason, the object oriented programming language C++ was chosen for relay model development. The paper describes the way of linking and and compiling of relay model with ATP. Next multifunctional digital relay developed model is introduced with its functional elements, used algorithms and tripping characteristics. Simulation results are presented and correct tripping action is verified at the end.

**Key-Words:** - Digital relay model, Foreign Model and C++, EMTP-ATP compiling.

## 1 Introduction

Computer simulation of an interactive protection system in general includes modelling of the power system, modelling of the protection relay itself and of the dynamic interaction between the power system and the digital relay. This type of simulation is useful especially for preparatory testing of new protection relay algorithms, co-ordinated protection systems and for evaluating the relay performance.

This paper describes a highly efficient approach to simulating the interactive protection system. In this case the power system is modelled in ATP and the digital relay model is developed in C++ programming language, which allows to program a highly sophisticated relay, and consecutively linked and compiled with the source code of ATP. Software package MinGW32 is used to link the relay source code with ATP and next compile. Mutual interaction of the two models is then accomplished in MODELS language by using the submodel „foreign model“, which ensures exchange of data between the two models by four data arrays.

## 2 Linking and compiling procedure of ATP

Software package MinGW32 includes appropriate tools to link of the relay source code with ATP source code and to compile them. By *gcc.exe*, *g77.exe* and *make.exe* programs the fortran compiler will create the object file from FORTRAN ATP written in FORTRAN language

and C++ compiler will create the object file from the relay source code written in C++ language.

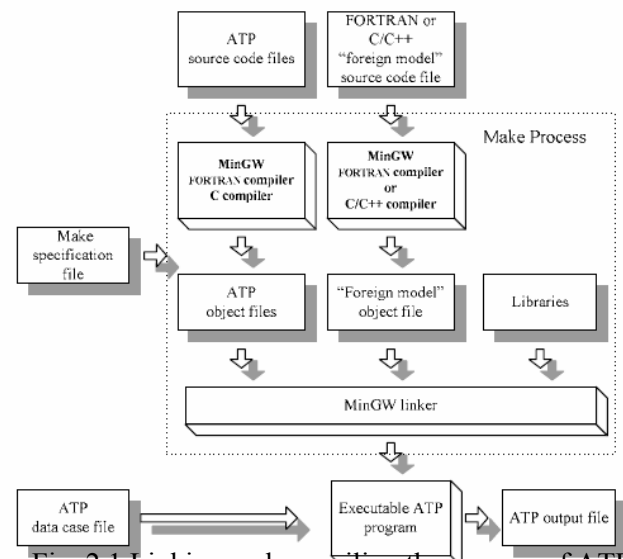


Fig. 2.1 Linking and compiling the process of ATP in MinGW32.

These will be subsequently linked with other object files and libraries and compiled, which will create a new simulation ATP program in file *tpbig.exe* containing a digital relay model in „foreign model“. Two variables, pointing to MingW32 and source code files, in Windows environment named, e.g., *GCC=C:\gcc-2.95.2\bin\* and *ATPMinG=C:\Eeug\LibMingw\* with respective values have to be created. The whole process is clearly described in Fig.2.1.

The file *makefile* makes a reference next on file *fgnmod.f* (Fig. 2.2), where MODELS language source code of „foreign model“ can be externally placed or C++ language relay model functions saved in a stand-alone file have to be declared. The name of this file is defined in *makefile*.

```

SUBROUTINE FGNMOD ( name, namlen, xdata, xin, xout, xvar, ini flg, ier flg)
  DATA refnam(3) / 'RELAY_C_MODEL' / - name of "foreign model" with local meaning
  ELSE IF (iname.EQ.3) THEN
    IF (ini flg.EQ.1) THEN
      CALL c_relay_i(xdata, xin, xout, xvar) - name of initializing function of relay model
    ELSE
      CALL c_relay_m(xdata, xin, xout, xvar) - name of executing function of relay model
    ENDIF
  RETURN
END
    
```

Fig. 2.2 Example of „foreign model“ definition in *fgnmod.f*.

Language MODELS is used for general description of the structure of models and the function of its elements. In comparison with high-level programming languages such as C++ its capabilities are considerably limited. To overcome these limits it includes „compiled foreign model“ mechanism, which allows to connect an external model developed in another programming language and in this way eliminate its limitations. This mechanism can be used for development of a sophisticated digital relay model in a higher programming language and by a pre-defined interface „foreign model“ connect this model with ATP. This interface is defined by four data arrays storing the values of model data, inputs, outputs and variables. Every model must have initializing and execution procedures. Before calling procedures in MODELS language these must be linked and compiled with ATP. After this there can be created any number of instances of a given model working independently of each other in the simulation, with directives controlling simulation specified in the USE declaration.

### 3 Multifunctional digital relay model

Multifunctional digital relay model is created in three files *relay.sup*, *relay.mod* a *relay.c*. First one represents componet in ATP-Draw and creates interface between relay model and user, by which he can connect this relay into power system and through dialog window to input relay settings. Second file represents part of relay model created in MODELS language. Sampling circuit and low-pass digital filter are created in it. Structer of relay model in MODELS language is on fig. 3.1.

Next it submits all datas to relay model created in c++ language by four data arrays, located in third file.

```

...
MODELS - Beginning of Models section in the ATP data file
/MODELS
INPUT ... - definition of inputs from the power system network
OUTPUT ... - definition of output to the power system network

MODEL relay - Declaration of overcurrent relay model
TIMESTEP - definition of sampling rate
INPUT - definition of input instantaneous values of current for the relay model
DATA - definition of relay characteristic settings
VAR - definition of auxiliary variables
OUTPUT - definition of relay model output
DELAY CELLS - definition of delay cells size of instantaneous current past values
HISTORY - definition of history values of current

MODEL C_RELAY FOREIGN RELAY_C_MODEL (ixdata:, ixin, ixout:, ixvar:) - definition of
foreign model of protection relay written in C++ file relay.c

EXEC
zfun(12/11)=(numerator)/(denominator) - expression of Z-transform transfer function of low-pass
discrete filter

USE C_RELAY AS C_RELAY - use statement of relay foreign model
DATA xdata[] =[] - set value of xdata[] for the foreign model
INPUT xin[] =[] - load inputs xin[] for the foreign model
HISTORY histdef(xvar[]) =[] - set history of xvar[] for the foreign model
OUTPUT [] =xout[] - set output from xout[] for the foreign model
ENDUSE

ENDEXEC

ENDMODEL

RECORD - specification of variables to be plotted

USE relay AS relay
INPUT ... - definition of inputs for relay model
DATA ... - definition of setting data for relay model
OUTPUT ... - definition of outputs for relay model
ENDUSE
ENDMODELS
    
```

Fig.3.1 Structure of digital relay model in MODELS

Interconnection of the relay model with the power system is made in section Models. This interconnection is represented by input values of the branch currents and voltages in individual phases measured through a circuit breaker and by the output value signals for disconnecting the circuit breaker and overreaching signal for second relay at the other end of line. The exchange of values between individual sections creates a hierarchical structure. The names of respective nodes in the power system are defined in INPUT and OUTPUT directives of Models section. The next values of Models section are available in the relay model by directives INPUT and OUTPUT in respective variables defined in Mode relay section. The required values by „foreign model“ are available from Model relay section by INPUT and OUTPUT directives defined in USE statement and given by four arrays *xdata*, *xin*, *xout* and *xvar*.

#### 3.1 Sampling circuit

Sampling circuit is created by TIMESTEP directive, which determines models frequency calling. By this way values are gained in regular time intervals from network and required number of samples is stored in buffer created by DELAY CELLS directive, depending on size of time-step. This samples are neede for filter operation and fourier analysis of each analysed quantity.

### 3.2 Digital filter

As a digital filter in relay low-pass Butterworth second order filter was chosen. It is represented by transfer function in z-area acquired from transfer function in Laplace area by z-transform. Respective function in model is entered by procedure ZFUN in form of ZFUN(Y/X)=NUMERATOR/DENOMINATOR.

Transfer function in z-transform for Butterworths filter generally has form as (3.1) and for second order filter by relationship (3.2)

$$H(z) = \frac{\sum_{k=0}^N a_k \cdot z^{-k}}{1 + \sum_{k=1}^N b_k \cdot z^{-k}} \quad (3.1)$$

$$H(z) = \frac{a_0 + a_1 \cdot z^{-1} + a_2 \cdot z^{-2}}{1 + b_1 \cdot z^{-1} + b_2 \cdot z^{-2}} \quad (3.2)$$

For cut-off frequency 200Hz and sampling frequency 500Hz frequency dependent behaviours of transfer and phase for second order Butterworths filter are shown on fig.3.2.

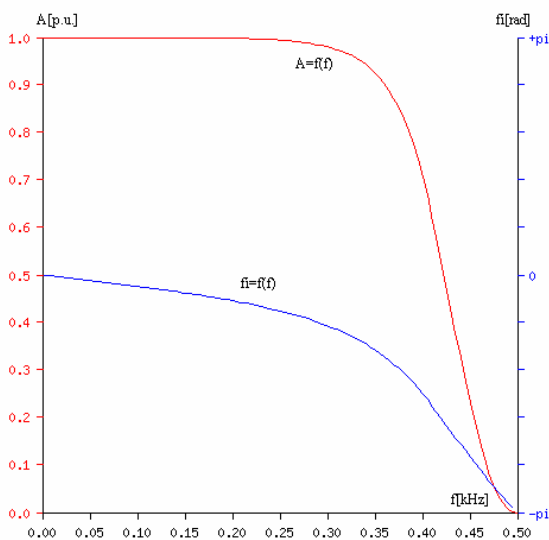


Fig.3.2 Frequency behaviour of Butterworth second order filter transfer and phase

### 3.3 Processing of filtered input signals

Input signals filtered from higher harmonics are next passed to relay model in c++, where they are processed by discrete fourier analysis. Filtering is necessary for reason of increasing fourier coefficients calculation accuracy. Discrete fourier analysis algorithm processes samples of input behaviours sampled in time intervals equal to value of TIMESTEP directive. It uses floating window what means that calculation of fourier series

coefficients is executed after every new sample and is not waiting for whole period to be sampled. Calculation of coefficients is by relationships in 3.3 for  $a_0$ , 3.4 for  $a_n$  and 3.5 for  $b_n$ .

$$a_0 = \frac{2}{T} \sum_{n=0}^m f(t) \cdot \Delta t \quad (3.3)$$

$$a_n = \frac{2}{T} \sum_{n=0}^m f(t) \cdot \cos\left(\frac{2 \cdot \pi \cdot n \cdot t}{T}\right) \cdot \Delta t \quad (3.4)$$

$$b_n = \frac{2}{T} \sum_{n=0}^m f(t) \cdot \sin\left(\frac{2 \cdot \pi \cdot n \cdot t}{T}\right) \cdot \Delta t \quad (3.5)$$

The final behaviour is formed by (3.6),

$$f(t) = \frac{1}{2} a_0 + \sum_{n=1}^k a_n \cos\left(\frac{2 \cdot \pi \cdot n \cdot t}{T}\right) + \sum_{n=1}^k b_n \sin\left(\frac{2 \cdot \pi \cdot n \cdot t}{T}\right) \quad (3.6)$$

or like (3.7),

$$f(t) = \frac{1}{2} a_0 + \sum_{n=1}^k \sqrt{a_n^2 + b_n^2} \cdot \sin\left(\frac{2 \cdot \pi \cdot n \cdot t}{T} + \arctan\left(\frac{b_n}{a_n}\right)\right) \quad (3.7)$$

from which by definition of the root mean square value we can formulate (3.8),

$$I_{RMS} = \sqrt{\frac{1}{T} \int_0^T \left( \frac{1}{2} a_0 + \sum_{n=1}^k \sqrt{a_n^2 + b_n^2} \cdot \sin\left(\frac{2 \cdot \pi \cdot n \cdot t}{T} + \arctan\left(\frac{b_n}{a_n}\right)\right) \right)^2 dt} \quad (3.8)$$

and by next modification for direct, fundamental and higher harmonic frequency components we get expression (3.9),

$$I_{RMS} = \sqrt{\frac{a_0^2}{4} + \sum_{n=1}^k \frac{a_n^2 + b_n^2}{2}} \quad (3.9)$$

The way of multifunctional digital relay model in c++ operation is that in its every execution it calls functions for fourier series coefficients calculation and RMS values of currents and voltages stated in main part. Impedance in each phase, current and voltage zero symmetrical components are calculated from them by calling respective functions. This values are input parameters for relay protection functions where they are evaluated.

Multifunctional relay includes nondirectional overcurrent relay with double set-stage tripping characteristic as shown on fig.3.5. It is suitable to set it as backup relay for other relays. It monitors values of currents in each phase and in case of exceeding setted limit it activates tripping signal after expiring respective

time stage. In case of one phase automatic reclosure setting after expiring entered time interval it activates signal for switch closing and if fault is permanent after expiring instantaneous time stage (for reason of nonsensitivity to emerging transient phenomena) definite switch-off signal is generated. In case of fault clearing during auto-reclosure time interval auto-reclosure automatic is blocked for next 5s. Each relay can be used individually or any combination from them depends only on its settings.

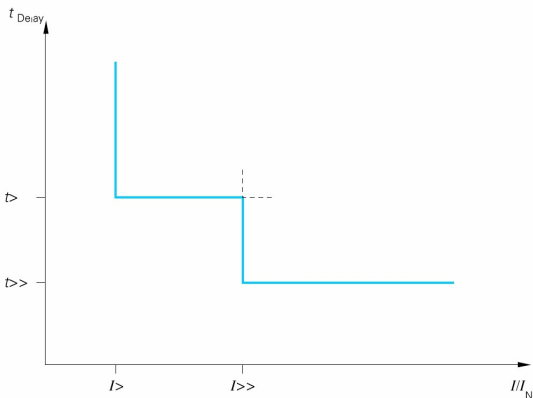


Fig.3.5 Double stage definite-time overcurrent characteristic

Second relay is directional overcurrent relay with double set-stage tripping characteristic shown on fig.3.5 for zero sequence symmetrical current component. It is suitable for ground fault protecting during which for reason of nonsymmetry zero sequence current emerges. It also includes three phase auto-reclosure automatic.

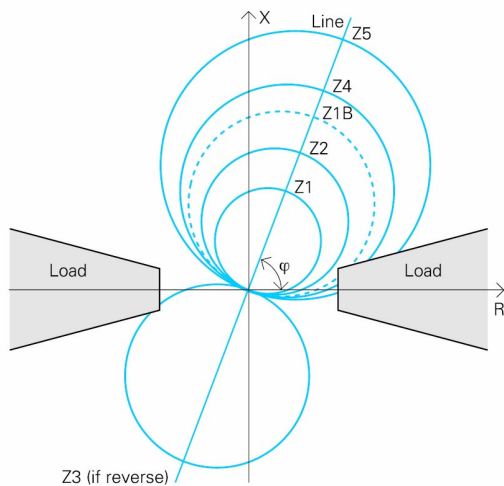


Fig.3.6 Offset MHO distance relay tripping characteristic

Next one is distance relay with tripping characteristic offset MHO as shown on fig.3.6. In order to guarantee a reliable discrimination between load operation and short-circuit – especially on long high loaded lines - the relay is equipped with a selectable load encroachment

characteristic. Impedances within this load encroachment characteristic prevent the distance zones from unwanted tripping. This relay is next equipped with one phase auto-reclosure automatic and in case of fault in first distance zone it activates a signal for opposite relay at the other end of the line to overreach first distance zone what ensures a switching-off a fault on the line in instantaneous time and enables auto-reclosure automatic for successful fault clearing.

Last relay is ground distance relay with quadrilateral tripping characteristic shown on fig.3.7. It is used for clearance of ground faults, it includes three phase auto-reclosure automatic, Load areas and overreaching distance measuring function.

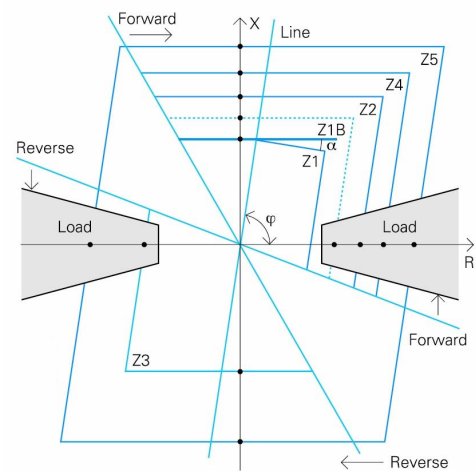


Fig.3.7 Quadrilateral tripping characteristic of ground distance relay

### 4 Application

As an example of relay model correct function a simulation of power system and relay connection on fig.4.1 is presented next. This example is modeled in ATPDraw with ground faulted phase A in 10% distance of line length from line beginning, arising in time 0,3s. Functionality of low-pass digital filter is with time behaviour of current and its RMS value calculated by relay shown on fig.4.2. Time behaviours of currents and current RMS values calculated by relays at the beginning and at the end of line are on figures 4.3 and 4.4.

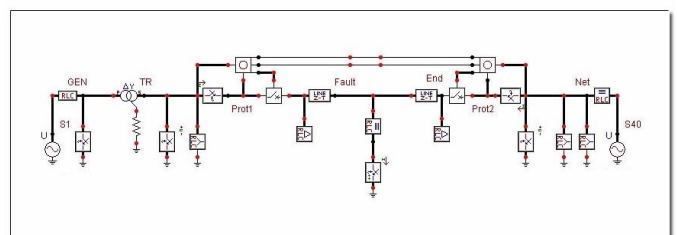


Fig.4.1 Example of power system and relay connection

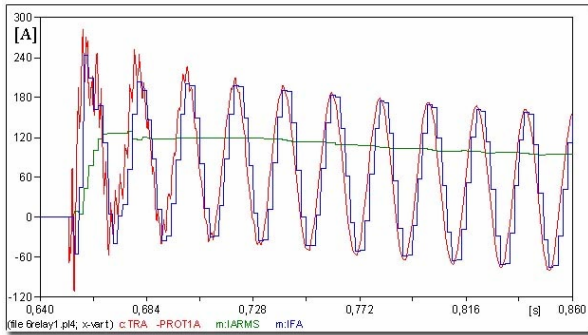


Fig. 4.2 Time behaviour of instantaneous current value and the output from digital filter

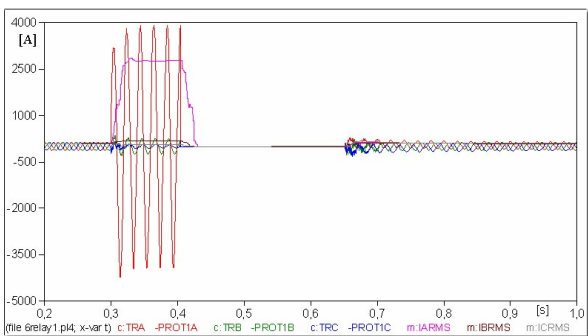


Fig. 4.3 Time behaviour of instantaneous and RMS values of currents at the beginning of line

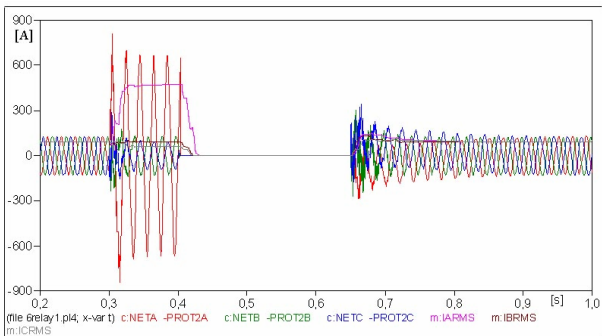


Fig. 4.4 Time behaviour of instantaneous and RMS values of currents at the end of line

From above behaviours it is evident, that relay at the end of the line tripped in overreaching distance zone, activated by opposite relay, in instantaneous time stage. Three phase auto-reclosure automatic timer was activated with time interval 0.25s, which after successful fault clearance connected the line to power system and after subsiding of transient phenomena the system continued in stable operation. Auto-reclosure automatic after this was blocked for 5s time interval. From behaviours of zero sequence impedance on fig. 4.5 and fig. 4.6 it is clear, that the tripping signal was activated by ground distance relay with setting of first distance zone on 85% line length with time delay stage 0,1s in first relay on  $R1=23,8\Omega$ ,  $X1=24,65\Omega$  and in second relay on  $R1=1,7\Omega$ ,  $X1=5,95\Omega$ .

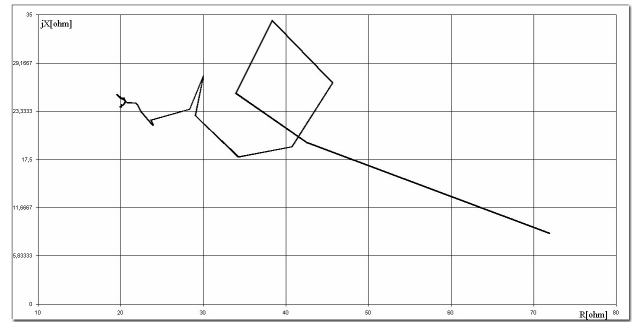


Fig. 4.5 Behaviour of zero impedance symmetrical component seen by relay at the beginning of line

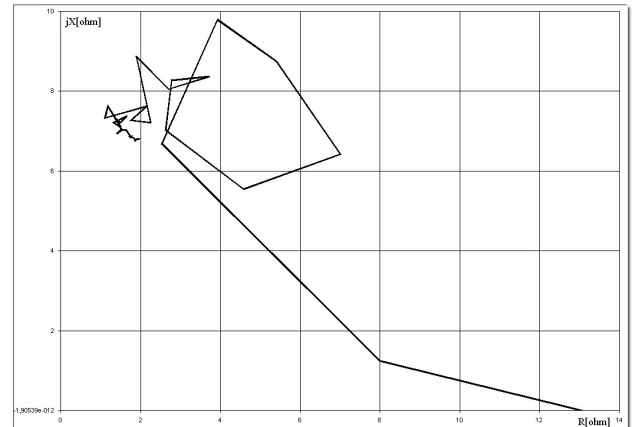


Fig. 4.6 Behaviour of zero impedance symmetrical component seen by relay at the end of line

In second case three phase fault on line was simulated in 10% distance of line length from line beginning. Time behaviours of currents and current RMS values calculated by relays at the beginning and at the end of line are on figures 4.7 and 4.8.

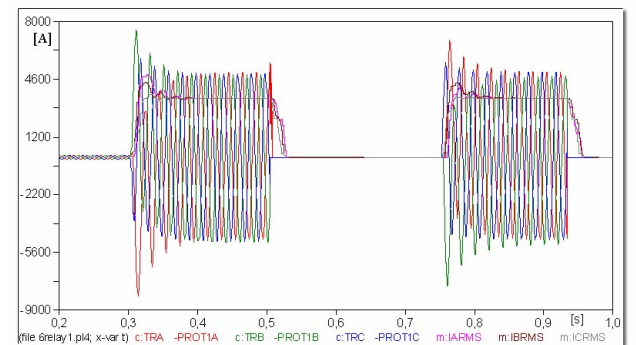


Fig. 4.7 Time behaviour of instantaneous and RMS values of currents at the beginning of line

From behaviours on fig. 4.7 and fig. 4.8, we can see, that both relays tripped in instantaneous time set-stage 0,2s and the second relay overreached its measuring distance first zone on first relay impulse. After line switching-off auto-reclosure automatic timer was activated and after 0,25s time interval connect permanent faulty line what after instantaneous time stage led to definite line disconnection. From behaviours of each phase

impedance on fig. 4.9 a fig.4.10 it is evident, that in multifunctional relay the distance relay tripped this fault with setting of first zone on 85% line length and time stage instantaneous setting on 0,2s in first and second relay on  $Z1=295\Omega$ .

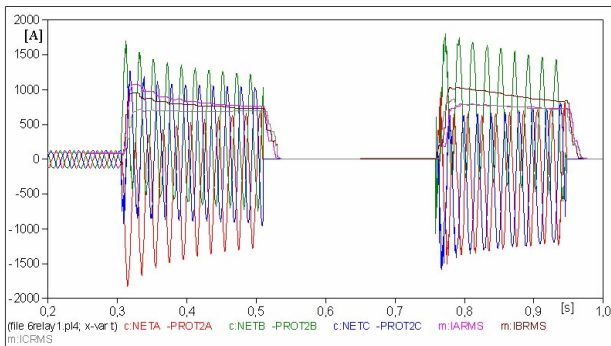


Fig.4.8 Time behaviour of instantaneous and RMS values of currents at the end of line

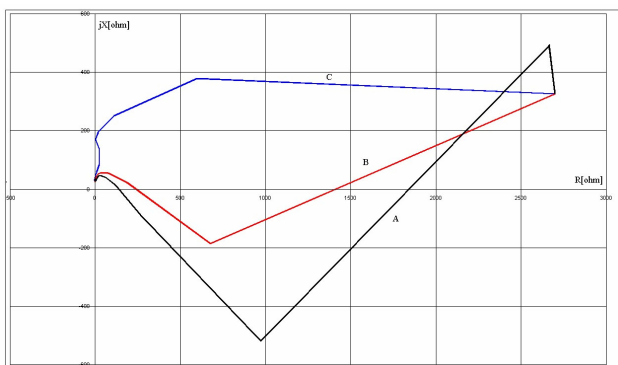


Fig.4.9 Behaviours of each phase impedances seen by relay at the beginning of line

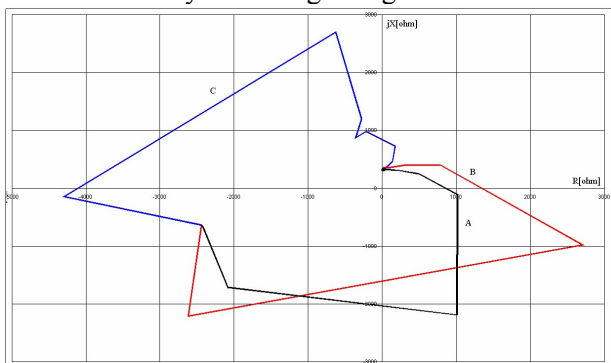


Fig.4.10 Behaviours of each phase impedances seen by relay at the end of line

## 5 Conclusion

This paper described a powerful approach to simulation of an interactive protection system, which is an ATP simulation program connected with a „foreign model“ programmed in high programming language C++ appropriate for development and testing of new relay algorithms. This article gives specific information about linking of C++ model and compiling with ATP. Next

developed multifunctional digital relay is presented here with described individual components. Finally, correct performance of the multifunctional digital relay is verified by simulation. The future work will be the development of this digital relay and a new protection algorithms for protecting medium voltage networks with isolated or resonant earthed neutral point.

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