Time Domain Simulation for Fault Locator Design using MODELS

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Abstract —— In this paper, a time domain model of a fault locator is represented using the MODELS language in the ATP version of EMTP. The fault locator model consists of five parts, which are input analog filter, sampling hold and digital filters, magnitude and phase calculation, fault locating algorithm, and statistical output procedure. Using different simulation cases, various fault types are modeled, considering the fault resistance to be constant or nonlinear. The calculated results are presented and discussed, and confirm the validity of representing the fault locator in a time domain simulation using MODELS.

Keywords: Fault locator, Time domain simulation, MODELS, EMTP, ATP

I. INTRODUCTION

Many fault locator algorithms have been developed to operate on digital relay data.[1]-[5] These methods are derived from frequency domain equations and were established by phasor simulation. These algorithms make the assumption that a fault arc has constant impedance and does not have any nonlinear effect. But in the real world, a fault arc may behave nonlinearly due to the variation of its physical characteristics. In such cases, the fault locating algorithm is in error due to the nonlinearity of the fault resitance. So some kind of statistical procedure must be used to reduce this error. Adequate filtering of input data is also required.

To study countermeasures to these nonlinear effects, time domain simulations must be performed considering the nature of the arc. In this paper, a time domain model of a fault locator is represented using the MODELS language in the ATP version of EMTP. Using different simulation cases, various fault types are modeled, considering the fault resistance to be constant or nonlinear. The calculated results are presented and discussed, and confirm the validity of representing the fault locator in a time domain simulation using MODELS.

The proposed approach has already been used on a real system, and shows satisfactory performance. The simulations described in this paper were conducted to study possible improvements to its present implementation.

The paper neglects the effect of a ground potential rise, as it is the authors' opinion that this effect is not understood well enough theoretically to be represented meaningfully in a simulation.

II. FAULT LOCATOR ALGORITHM

Fault locators are used to help rapid restoration of faulted power transmission lines. The history of the fault locator is old, and many fault locator algorithms have been developed. In recent years, many digital relay type fault locator algorithms have been proposed. These algorithms are divided into two categories, one using data from one terminal of a transmission line, and the other using data from both terminals. The former is superior in the viewpoint of economy because it needs no data transfer along long distance. The latter is superior in the viewpoint of correctness of fault location but this method needs a data transfer system.

In this paper, we deal with one-terminal type fault locator. The power systems to which the fault locator is applied, are the 66, 77 and 154kV high-resistance grounded systems largely used in Japan. One application is for a radial circuit (Fig.1) and another is for a double circuit (Fig.2). We focus on the ground fault because the locating error for this type of fault is strongly affected by the nonlineality of the fault resistance.

A. Fault locating for radial circuit (using the impedance relay type method)

$$X = \frac{\mathrm{Im}(V \cdot I^*_{pol})}{\mathrm{Im}(V_u \cdot I^*_{pol})} \qquad (1)$$

$$V_u = Z_s \cdot I + \sum Z_m I_{other}$$

where

X: distance from locating point to fault point
V : fault phase voltage of locator terminal
V_u: line drop voltage (per unit length)
Z_s: self impedance (per unit length)
Z_m : mutual impedance (per unit length)
I :faulted phase current of locator terminal
I_{other} : unfaulted phase current of locator terminal
$I_{pol} = 3 \cdot I_o = I_a + I_b + I_c$
Im( ): imaginary part
A^*: conjugate of A

B. Fasult locating for double circuit (using the current diversion ratio method)

$$X = \frac{2 \cdot \mathrm{Re}(I_{0m} \cdot V^*_{pol})}{\mathrm{Re}\{(I_0 + I_{0m}) \cdot V^*_{pol}\}} \times l \qquad (2)$$

where

I_0 : zero sequence current of faulted line
I_{0m} : zero sequence current of another line
V_{pol}:$V_{BC}\angle 90^o$(case of a-phase locating)
Re( ): real part
l: transmission line length.

The locating calculation uses data within 60 seconds from when the fault occurred. Data is sampled a number of times per cycle. When the difference between the calculated result and the result calculated at the previous sample is within 0.5 km, and this repeats continuously three times, we consider that the calculation has converged. If it has not converged, we set the locating result to the value which has the least error of the three samples.

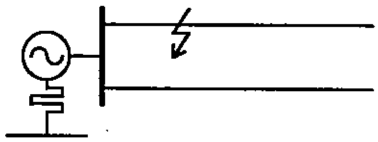

Fig.1. Radial circuit transmisson line

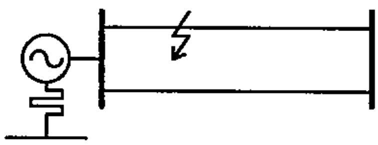

Fig.2. Double circuit transmisson line

III. FAULT LOCATOR MODEL DESCRIPTION USING MODELS

A time domain model of a fault locator is represented using the MODELS language in the ATP version of EMTP. The fault locator model basically consists of five parts:

1) Input analog filter
2) Sampling/hold and digital filters
3) Magnitude and phase calculation
4) Fault location algorithm
5) Statistical output procedure

These five procedures are applied in sequence. Each one is described in more detail below.

1) Input analog filter

Block 1 is used to eliminate, before sampling, any harmonics existing in the measured signals near the sampling frequency. The filtering is applied to all voltage and current measurements used by the fault locator. The filter is represented in the model by a constant-coefficient Laplace transfer function:

$$\frac{LN_0 \cdot s^0 + LN_1 \cdot s^1 + LN_2 \cdot s^2}{LD_0 \cdot s^0 + LD_1 \cdot s^1 + LD_2 \cdot s^2 + LD_3 \cdot s^3}$$

where the numerator and denominator coefficients are provided as data to the model when the model is used.

2) Sampling/hold and digital filters

Block 2 represents the analog to digital conversion applied by the digital fault locator. The filtered signal is sampled 12 times per second,that is,at a sampling interval larger than the time step of the simulation. This sampling is modeled by placing the digital filter in a submodel that uses a larger time step corresponding to the required sampling period. This is specified in that submodel as follows:

```
MODEL digital_filter
  DATA sampling_iterval
  TIMESTEP MIN: samplong_interval
  etc...
ENDMODEL
```

The size of the sampling interval is specified when the model is used. Its value is then used automatically by the model as the model's time step.

As for the digital filtering, it is represented by a constant-coefficient Z transfer function:

$$\frac{1 \cdot z^0 + 2 \cdot z^{-1} + 1 \cdot z^{-2} - 1 \cdot z^{-4} - 2 \cdot z^{-5} - 1 \cdot z^{-6}}{1 \cdot z^0}$$

3) Magnitude and phase calculation

In block 3,the real and imaginary parts of the phasor representation of the sampled and filtered signal *yf* are calculated using a single term of the discrete Fourier series evaluated at the power frequency. The calculation is kept simple by using an incremental approach,as shown below, where *Yr* is the calculated real part at frequency *omega*:

```
Yr_delta:=2/n*yf*cos(omega*t)
Yr:=Yr+Yr_delta
      -delay(Yr_delta,sampling_period)
```

and *Yi* is the imaginary part:

```
Yi_delta:=-2/n*yf*sin(omega*t)
Yi:=Yi+Yi_delta
      -delay(Yi_delta,sampling_period)
```

The magnitude *Ya* and phase angle *Yp* of the phasor at that frequency are then obtained directly from the real and imaginary parts:

```
Ya:=norm(Yr,Yi)
Yp:=deg(atan2(Yi,Yr))
```

4) Fault locating algorithm

Block 4 describes the fault location derived in the time domain. For both the impedance-type calculation and the current diversion ratio calculation, the phasor equation is expanded in terms of the real and imaginary parts of the currents and voltages.

For the impedance-type model, the fault distance is calculated as shown in eq.(1). The corresponding part of the model is written as follows:

```
Ipolr := Ir[1] +Ir[2] +Ir[3]
Ipoli := Ii[1] +Ii[2] +Ii[3]
Vur   := 0
Vui   := 0
FOR k:=1 TO 3 DO
  Vur := Vur +Zr[k]*Ir[k] -Zi[k]*Ii[k]
  Vui := Vui +Zr[k]*Ii[k] +Zi[k]*Ir[k]
ENDFOR
dist := abs((Vi*Ipolr -Vr*Ipoli)
        *recip(Vui*Ipolr -Vur*Ipoli))
```

where:

Ir, Ii	current phasor for each phase (real and imaginary)
Ipol	3 times the zero-sequence current
Zr, Zi	line impedance per unit length (real and imaginary)
Vur, Vui	line drop voltage per unit length (real and imaginary)
dist	calculated fault distance at each sampling

In the case of the current diversion ratio method, the fault distance is calculated according to eq.(2). This is specified in the model as follows:

```
Izr := (Ir[1] +Ir[2] +Ir[3])/3
Izi := (Ii[1] +Ii[2] +Ii[3])/3
Izrefr := (Ir[4] +Ir[5] +Ir[6])/3
Izrefi := (Ii[4] +Ii[5] +Ii[6])/3
Vbcr := Vr[2] -Vr[3]
Vbci := Vi[2] -Vi[3]
Vbca := norm(Vbcr,Vbci)
Vbcp := deg(atan2(Vbci,Vbcr))
Vpola := Vbca
Vpolp := Vbcp +90
Vpolr := Vpola*cos(rad(Vpolp))
Vpoli := Vpola*sin(rad(Vpolp))
dist := abs(2*line_length
        *(Izrefr*Vpolr +Izrefi*Vpoli)
        *recip( (Izr+Izrefr)*Vpolr
               +(Izi+Izrefi)*Vpoli))
```

where:

Ir, Ii	current phasor for each phase (real and imaginary)
Iz	zero-sequence current phasor
Izref	zero-seq. current of reference line
Vr, Vi	voltage phasor for each phase (real and imaginary)
Vbc	Vph-ph phasor of unfaulted phases
Vpol	Vbc rotated by 90 degrees
dist	calculated fault distance at each sampling

5) Statistical output procedure

Block 5 is the statistical procedure applied to reduce the error due to the nonlinearity of the fault arc resistance. The three most recent values of the calculated fault distance are stored and updated at each sampling:

```
cdist[0] := cdist[1]    -- sample n-2
cdist[1] := cdist[2]    -- sample n-1
cdist[2] := dist        -- sample n
```

The differences between the distance values are also stored and updated:

```
ddist[0] := cdist[1]
ddist[1] := abs(cdist[2]-cdist[1])
```

The differences are used to determine if the calculated values converge to within 0.5 km, using the following logic:

```
IF NOT converge THEN
  IF ddist[0..1]<=0.5 THEN
    converge := TRUE
  ENDIF
ELSIF ddist[1]>0.5 THEN
  converge :=FALSE
ENDIF
dist_result := converge*cdist[0]
```

The final variable *dist_result* will then show a non-zero value whenever the distance calculation has converged.

IV. SIMULATION EXAMPLES

In this section, using different simulation cases, various fault types are modeled, considering the fault resistance to be either constant or nonlinear.The constant resistance is 100 ohms. The nonlinear resistance representing the arc resistance is calculated as follows:

$$G := \frac{abs(i)}{(u + Rarc \cdot abs(i)) \cdot len}$$

$$CLAPLACE(gf/G) := \frac{1 \cdot s^0}{1 \cdot s^0 + tau \cdot s^1}$$

$$R := len \cdot recip(gf)$$

where:

u	10V/cm	characteristic arc voltage
Rarc	55mΩ/cm	characteristic arc resistance
tau	0.4ms	arc time constant
len	580cm	arc length

The calculated results for a line-to-ground fault in a radial circuit (Fig.1), using the impedance method, are presented in Fig.3. In this case, the distance to the fault point is 5 km. When the fault resitance is constant, the fault location is correct. But when the fault resistance is nonlinear, a significant location error is observed. This error is due to the nonlinear characteristic of the fault resistance. The statistical output procedure should be modified to compensate for this error.

The calculated results for a line-to-ground fault in a double circuit (Fig.2), using the current diversion ratio method, is presented in Fig.4. In this case, the line length is 20 km and the distance to the fault point is 5 km. When the fault resitance is constant, the fault location is correct. And also when the fault resistance is nonlinear, no significant location error is observed. This is based on the fact that this fault locating algorithm is only using current information as shown earlier. So, the fundamental component of zero-sequence currents satisfy the equation even if the fault resistance is nonlinear.

V. CONCLUSIONS

To study countermeasures to the nonlinear effects of the fault resistance, time domain simulations must be performed considering the nature of the arc. In this paper, a time domain model of a fault locator was represented using the MODELS language in the ATP version of EMTP.

In the simulation two fault types are modeled. One is constant fault resistance and another is considering the fault resistance to be nonlinear. The calculated results are presented and the validity was confirmed of representing the fault locator in a time domain simulation using MODELS simulation language.

The effect of a ground potential rise on the simulation is a remaining problem that requires further consideration.

VI. REFERENCES

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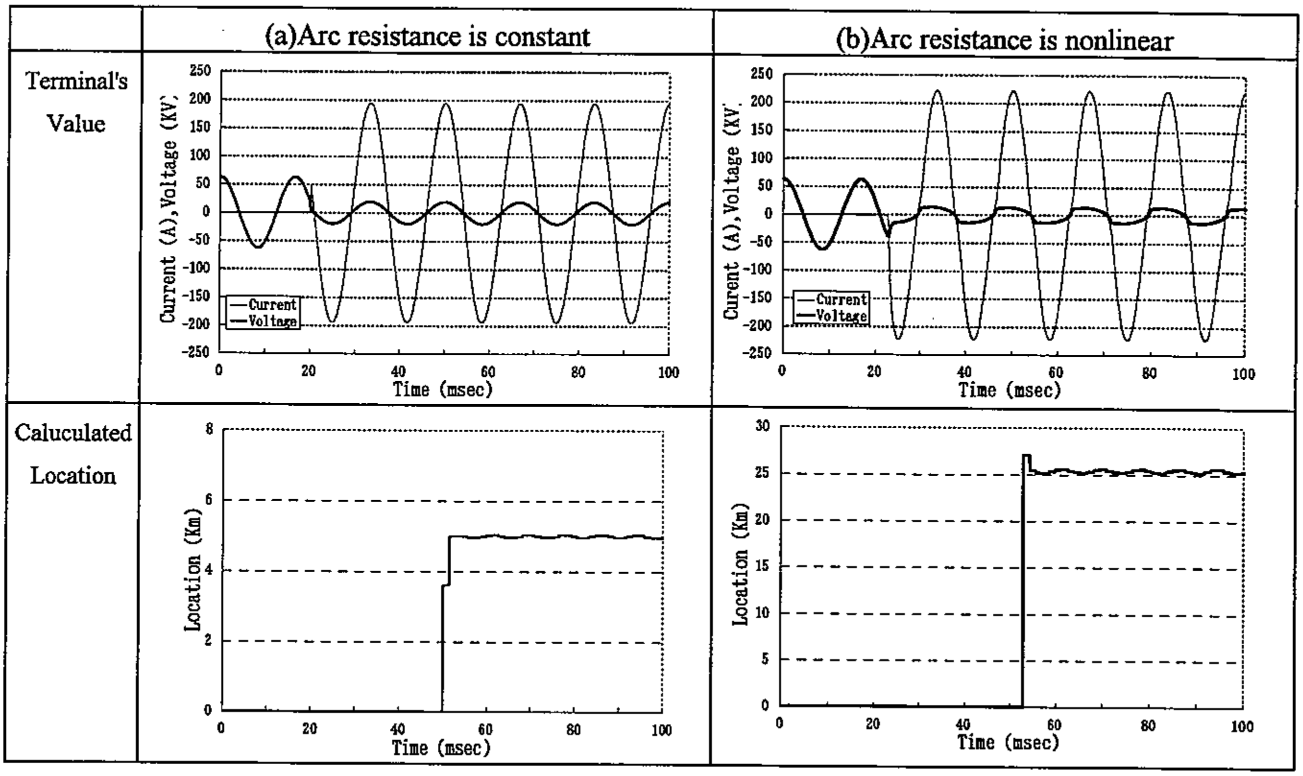

Fig.3 Calculated results for radial circuit

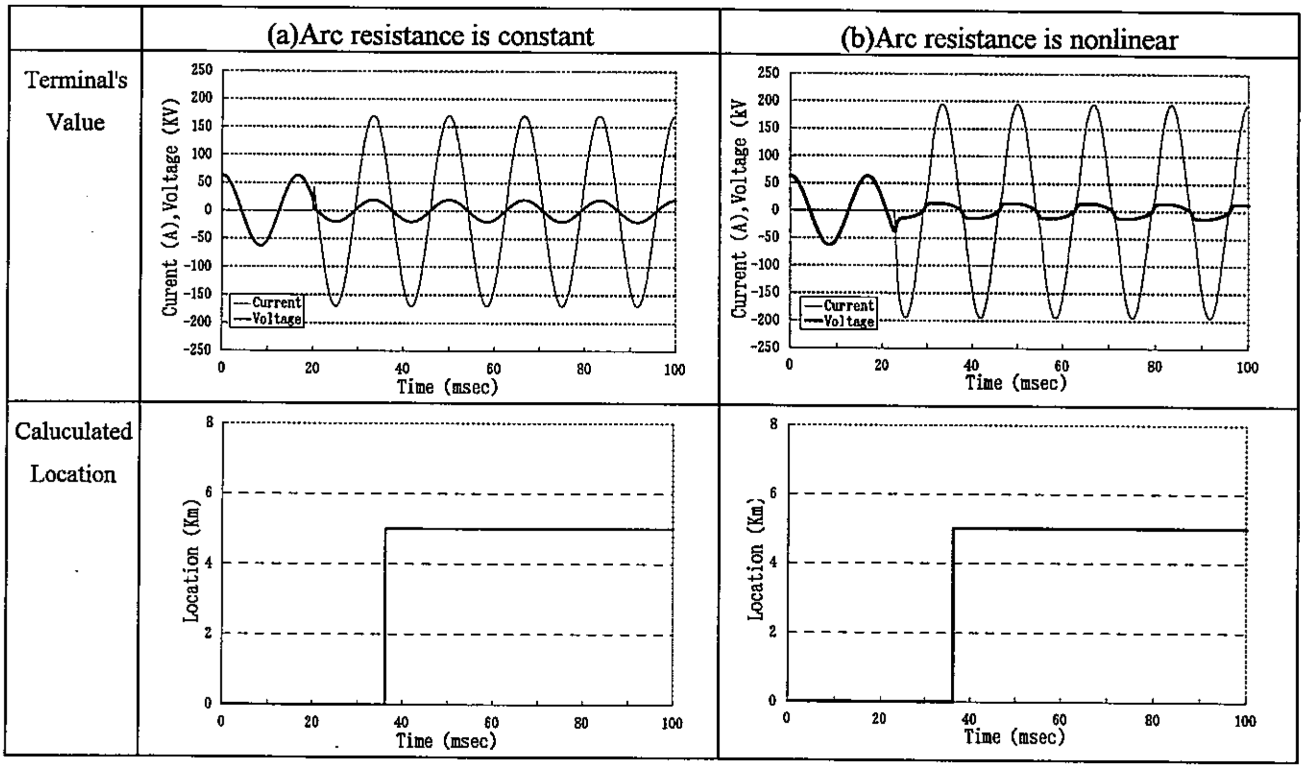

Fig.4. Calculated results for double circuit