I NSTRUMENT TRANSFORMERS

Instrument transformers are used to reduce power system signal levels for application to protection equipment. During a transient, instrument transformers must reproduce the primary signal at a lower level as accurately as possible.

4a.1 CT MODEL

Typically, current transformers are designed to operate well within the linear region of the fluxïcurrent plane. But, under heavy fault conditions the current transformer may saturate and clearance of a fault can leave behind remanent flux on the core. A BïHloop (flux vs. magnetizing current) defines the magnetizing characteristic of the CT core material. A typical Bï H loop is shown in Figure 4.1. Assuming that the CT core is initially unmagnetized, during fault conditions, as the magnetizing current increases the flux increases according to line aïb and may eventually saturate. After the fault is cleared, the magnetizing current decreases, and the flux follows the path bïc. As can be seen from Figure 4.1, there is still flux in the core as line aïc represents, this is referred to as remanent flux.
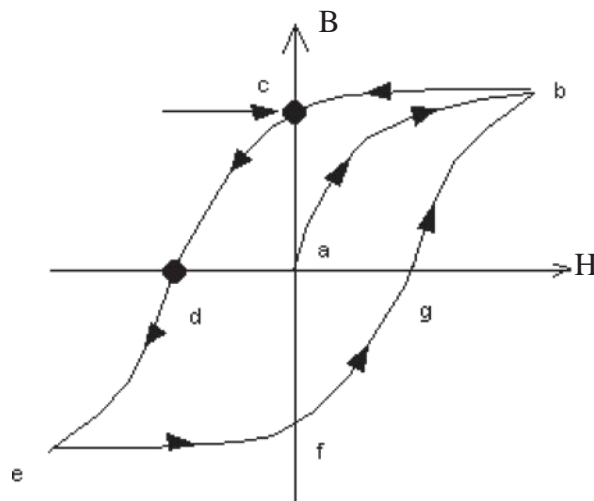

Figure 4.1 BïH Loop

Due to the remanent flux, upon reclosing the breaker, distorted waveforms can be presented as input to the relay. As this is particularly important aspect of protection, the example presented in this chapter will demonstrate this.

4a.2 POWER SYSTEM MODEL

The simple circuit used as the example is shown in Figure 4.2. The power system consists of a 230 kV source model connected to a three phase breaker and an RL load. The source impedance is set to 10∠80 and the load parameters are R=180.0ˆ and L=0.45H. In addition to the load, a phase to ground fault branch is connected. The circuit below was constructed using single line diagram components from the Power System library tab.

Single Line Diagram (SLD) View
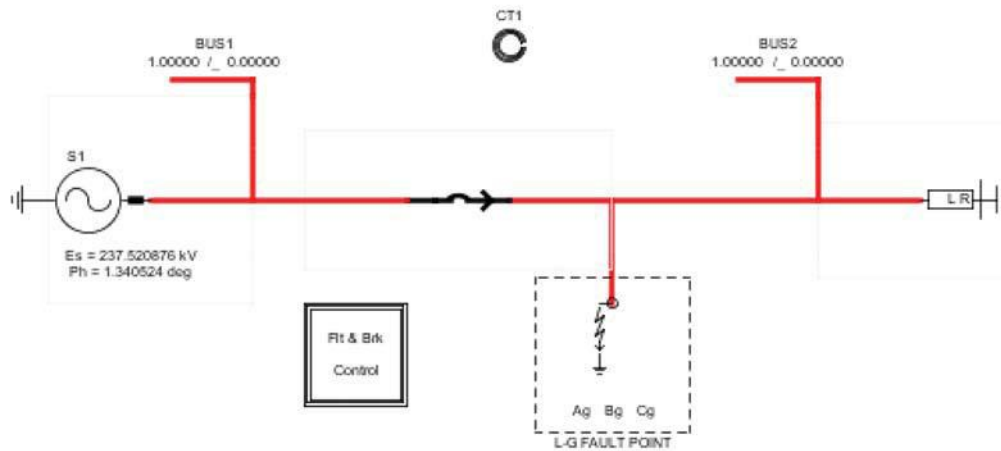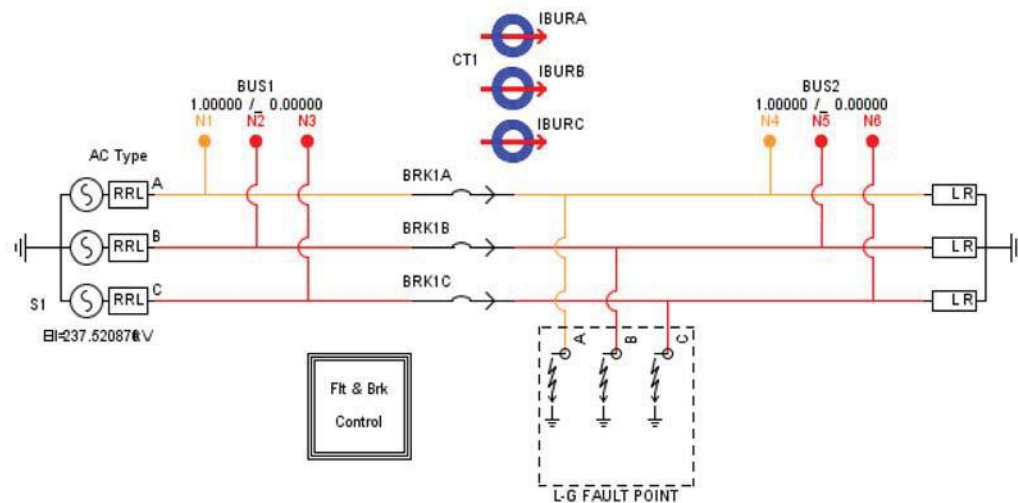
Three Phase View (3PH)

Figure 4.2 CT Model Example

In the Draft circuit shown in Fig 4.2, the CT model is not attached to any other component. The reason being that the CT model does not contribute to the simulation and is used only to provide secondary signals for interfacing to external protection equipment. The CT model requires the primary current as input and this is entered into the CT model by name. The CT model main menu is shown in Figure 4.3.

If_rtds_sharc_sld_CTV2

PRE-PROCESSOR VARIABLE (PPV) SELECTION	PPV NAMES	PPV MAXIMUM VALUES
V1,I1 … V10,I10	P-LOSS DATA	MONITORING	SIGNAL NAMES
MAIN DATA	PROCESSOR ASSIGNMENT	TRANSFORMER DATA	BURDEN

Name	Description	Value	Unit	Min	Max
NAME	CT Unit Name	CT1			
SIGA	A Phase Primary Current Signal Name	IBA			
SIGB	B Phase Primary Current Signal Name	IBB			
SIGC	C Phase Primary Current Signal Name	IBC			
F	Frequency	60.0	Hz	0	
DE	Core characteristics data entry	Vrms.Irms ▼			
csa	Cross-sectional Area	1.19532e-3	m^2	0.0	100
PLen	Path Length	0.4987	m	0.0	100
FLXRS	Enable Flux Reset?	No ▼		0	1
ENRMN	Enable The Initial Remanence?	No ▼		0	1
FIT	BH Curve Fitting Algorithm	Least Squre ▼			
prtyp	Solve Model on card type:	GPC/PB5 ▼		0	2

Update   Cancel   Cancel All

Figure 4.3

The primary current input is entered in the SIGA, SIGB and SIGC parameter box. From the circuit diagram in Figure 4.2, the current IBA, IBB and IBC is the circuit breaker current.

In this example the CT data in reference [2] is used.

Turns Ratio: 180 (900A primary, 5A secondary)

Secondary Side Resistance: 0.253 ˆ Secondary

Side Inductance: 0.8eï3 H

Burden Series Resistance: 20.0 ˆ

Burden Series Inductance: 35eï3 H

A high burden was chosen so saturation would occur at low current levels. The burden current is given by equation 4.1.

I_{bur} I_{sec} I_{mag} equation 4.1 therefore if the burden current is small, the magnetizing branch draws more current.

Typically, CT data is obtained from the manufacturer. The saturation data is usually given in the form of a Vrms vs. Irms curve. Due to the lower current level of the CT secondary, laboratory tests can be performed on the secondary side to determine the Vrms and Irms values. Therefore, the CT Vrms and Irms data is usually available and used in this example.

CT saturation characteristics can also be entered as BïHvalues or physical core data. If this type of data entry is used to define the saturation characteristic, then the path length and cross sectional area of the core must be known. The path length and cross sectional area are defined by the dimensions of the ring type core as shown. The path length is the circumference of the core.
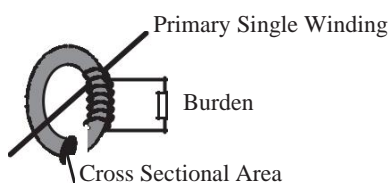
To enter the CT saturation data in Vrms and Irms values,

Sselect the **MAIN DATA** tab from the CT parameters menu

Sgo to the Core characteristics data entry parameter

Sselect the Vrms,Irms option from the pull down menu

CT Saturation Data

Vrms (Volts)	Irms (Amps)
85.0	0.04
90.0	0.045
105.0	0.05
120.0	0.075
130.0	0.0875
140.0	0.1
145.0	0.15
150.0	0.2
169.0	6.0
175.0	10.0

The loop width in the PïLOSS DATA tab is set to 10%.

The CT saturation values of reference [2] contained five data points. The RTDS CT model requires ten data points. The additional values required for the RTDS CT

model were extrapolated from the given Vrms–Irms curve. The RMS voltage and current values are converted to B and H values using equation 4.2 and 4.3 respectively.

$$B[n] = \frac{V_{rms} * \sqrt{2}}{\omega}$$ 　　　　　　equation 4.2

$$H[n > 2] = i_{n-1} + Y_n(B_n - B_{n-1})$$ 　　　equation 4.3

where: n is the number of saturation data points
$$H[0] = 0.0 \text{ and } H[1] = I_{rms} * \sqrt{2}$$
$$Y[n] = \frac{1}{L_n} \text{ and Ln is computed from the Vrms and Irms data}$$

The calculations used to determine H from the given Irms values is quite complicated. Please refer to reference[1] for more information.

Alternatively, the physical core data could be entered. Two parameters are required, the initial relative permeability of the core and the saturation flux density. The relationship between the core data and B–H values is determined using the Frolich equation shown in equation 4.4.

$$B = \frac{H}{(c + b|H|)}$$ 　　　　　　equation 4.4

The constants b and c can be found using equation 4.5. The permeability of the core is obtained by taking the derivative of the Frolich equation

$$\mu_0 \mu_r = \frac{dB}{dH} = \frac{(1 - b|B|)^2}{c}$$ 　　　equation 4.5

The initial relative permeability is a known value and occurs when B=0, when the slope of the B–H curve is maximum. Setting B = 0 in equation 4.5 gives equations 4.6 and 4.7 which define the constants b and c of the Frolich Equation.

$$b = \frac{1 - 1/\sqrt{\mu_i}}{B_{sat}}$$ 　　　　　　equation 4.6

$$c = \frac{1}{\mu_0 \mu_i}$$ 　　　　　　equation 4.7

where: $\mu_0 = 4\pi * 10^{-7}$ permeability of free space
μ_i initial relative permeability
B_{sat} saturation flux density

The converted B and H values are then used as input to equation 4.8 which defines the saturation characteristic.

$$H(t) = B_1 * B(t) + B_2 * B^{35}(t)$$ 　　　equation 4.8

A curve fitting technique is used to solve equation 4.8. Two curve fitting techniques are available, least square and fixed linear slope. The curve fitting algorithm can be selected from the CT MAIN DATA menu. Typically, the least square curve fitting algorithm is used, but in some instances the algorithm can fail. In this case, the fixed linear slope algorithm can be used, but the least square curve fitting algorithm is prefered.

During the simulation, the CT signals of interest are the burden current, the flux and magnetizing current. To monitor these values from RunTime, the signal names must be specified from the CT component in Draft. To enter the signal names,

> Sselect the **MONITORING** tab from the CT parameters
>
> menu Sgo to the Monitor Magnetizing Flux parameter
>
> Sselect B(Wb/m^2) from the pull down menu provided
>
> Sgo to the Monitor Magnetizing Current parameter
>
> Sselect Imag(A) from the pull down menu provided
>
> Sselect the **SIGNAL NAMES** tab from the CT parameters menu
>
> Senter the signals names for the burden current, flux and magnetizing current

4a.3 SENDING SECONDARY CURRENTS TO RTDS ANALOGUE OUTPUT CHANNELS

If this example case was being used to test a relay, the secondary currents or burden currents from the CT component would be used as input to an external device. This example is not going to be physically connected to a relay, but an example is shown in Figure 4.4 with the secondary current sent to RTDS analogue output channels.

Assume that the CT secondary current is to be sent to a GTAO card. A GTAO card is a peripheral card that provides twelve high precision analogue output channels. The CT secondary current is used as input to the GTAO component. An import/export component is used to export the signals IBURA, IBURB and IBURC from the power system and import the signals to the control block. The burden current signal names are assigned in the **SIGNAL NAMES** menu of the CT component.
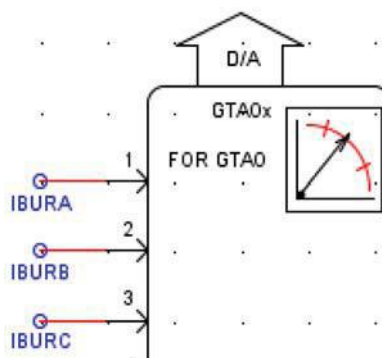

Figure 4.4 CT Secondary Currents sent to GTAO

The secondary current of the CT component can be used as input to any analogue output component. But, typically for protective relay applications a GTAO card

would be used. These cards have sixteen bit analogue output channels. During fault conditions the output current can be many times larger than the steady state value, so the sixteen bit precision of the above mentioned cards provide a wide dynamic range needed to accurately represent the output current.

4a.4 FAULT & BREAKER CONTROL

The three phase fault and breaker components can be added to the Draft circuit as shown in Figure 4.2. The breaker current names must be IBA, IBB and IBC. This is the primary current that the CT models are referencing as input.

Fault and breaker components can be set to operate on control words or signals. Through use of the controls components, an integer signal can be created and used to operate a switch component. A fault is applied on a logic 1 and cleared on a logic 0. A breaker is opened on a logic 0 and closed on a logic 1.

To illustrate the remanent flux trapped in the core after a transient has been applied, the event sequence in Figure 4.6 is going to be used. The most severe case is when the transient is applied at a zero crossing, this is also included in the controller.
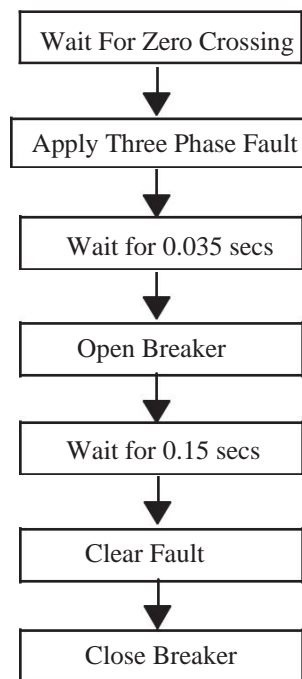
Wait For Zero Crossing

↓

Apply Three Phase Fault

↓

Wait for 0.035 secs

↓

Open Breaker

↓

Wait for 0.15 secs

↓

Clear Fault

↓

Close Breaker

Figure 4.6 Event Sequence

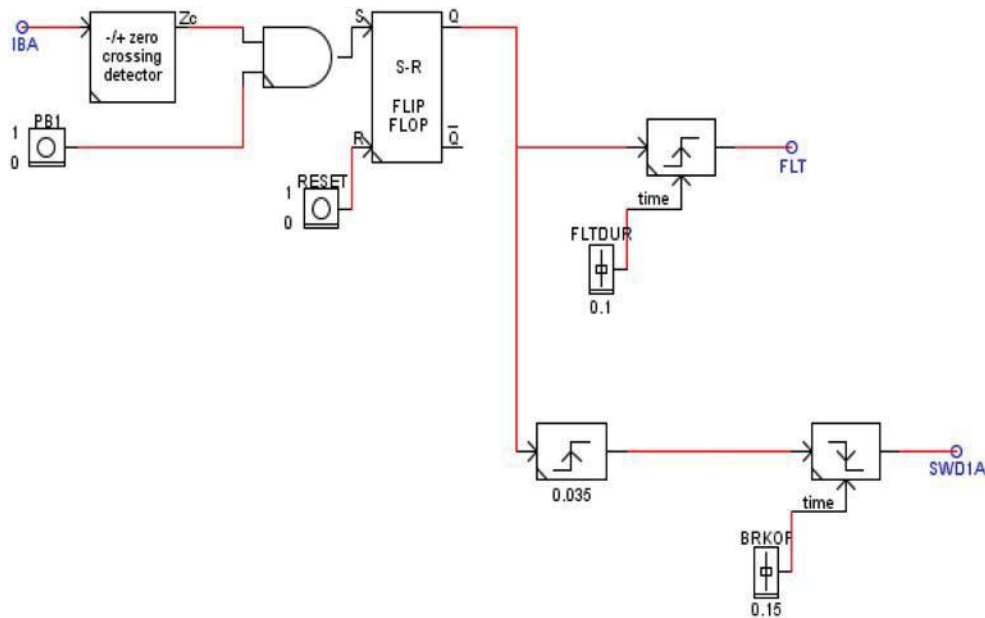The controls components used to create the event sequence in Figure 4.6 are shown in Figure 4.7.

Figure 4.7 Fault & Breaker

Controller The controller can be created by,

Sselecting the Controls library tab

Scopying and placing the controls components in the hierarchy component

In the controls library tab, control components have been grouped together based on their function. The zero crossing detector can be found in the "Signal Processing" group, the AND gate and Sï R flip flop can be found in the "Logic Functions" group, and the pulse generator can be found in the "Signal Generators" group.

The primary current is used as input to the zero crossing detector component. An import/export component is used to export the signal IBA from the power system and import the signal to the control blocks.

A controls pushbutton is going to be used to initiate the faultïbreaker control sequence. The zero crossing detector signal and the pushbutton signal are sent to an AND component. During the simulation from RunTime, if the primary current IBA has crossed above zero and the button has been pushed, the signal out of the AND component will be a logic 1. This control signal is then sent to a SïR flipflop which will hold the signal Q high until the flipïflop receives a reset signal. The signal Q is sent to two pulse generators, one which will control the fault, and the other to control the breaker.

The pulse generator used to control the fault is set to operate on a positive transition and will produce a 0ï>1 pulse for a duration of 0.1 seconds. The pulse duration can be set as a variable or fixed parameter. In this case the pulse duration has been selected as variable so the fault duration can be modified from RunTime using a slider. The

fault control signal has been given the name FLT. Control signals are labelled in Draft using wire labels. Any control signal identified with a wire label can be monitored from RunTime. The power system fault component has to be assigned to operate on the control signal FLT. To assign the control signal to the power system fault component,

> Sselect the **APhaseïGround Fault Branch Data** tab from the fault
> component menu.
>
> Sgo to the parameter named 'Asig ï Signal Name to control fault'
>
> Senter the fault control signal name FLT
>
> Sgo to the parameter 'Abit ï Active bit number in Asig to trigger fault'
>
> Senter the value 1

Now, phase A fault is assigned to be controlled on bit #1 of the signal named FLT. Phase B and C of the fault component must also be set to operate on the same FLT signal and bit. During the simulation, when the control signal FLT goes high (integer value of 1), a three phase fault will be applied.

The signal Q from the SïR flip flop is also sent as input to the breaker control blocks. The first pulse generator is set to operate on a positive transition and will produce a 0ï>1 pulse for a duration of 0.035 secs. This is used as a delay before opening the breaker. The next pulse generator is set to operate on a negative transition and will produce a 1ï>0 pulse for a duration of 0.15 secs. The pulse duration of the second block can be set to fixed or variable. In this case, variable was selected so the breaker operation time can be modified from RunTime using a slider. The breaker signal has been given the name SWD1A using a wire label. The power system breaker component has to be assigned to operate on the control signal SWD1A. To assign the control signal to the power system breaker component,

> Sselect the **A Phase Breaker Data** tab from the breaker parameter menu.
>
> Sgo to the parameter named 'Asig ï Signal Name to control breaker'
>
> Senter the breaker control signal name SWD1A
>
> Sgo to the parameter 'Abit ï Active bit number in Asig to control breaker'
>
> Senter the value 1

Now, phase A of the breaker is assigned to be controlled on bit #1 of the signal named SWD1A. Phase B and C of the breaker must also be set to operate on the same SWD1A signal and bit. During the simulation, when the control signal SWD1A goes low (integer value of 0), the three phase breaker will open.

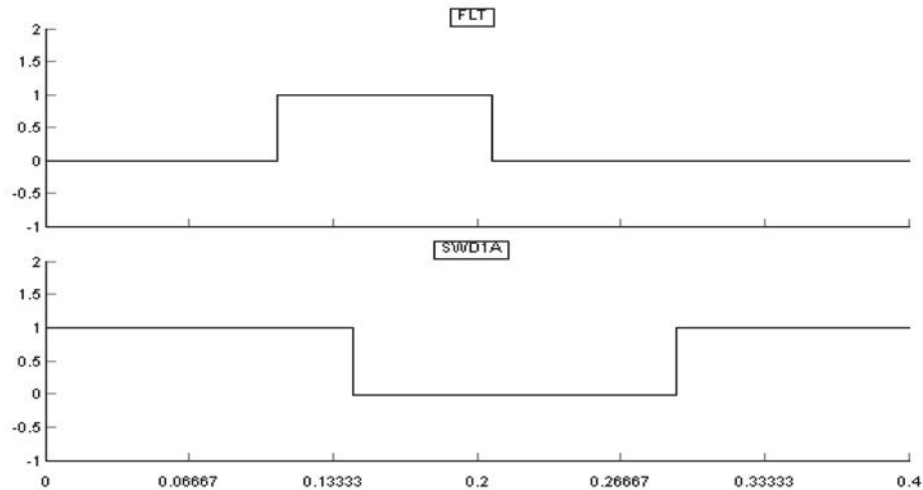A plot of the control signals FLT and SWD1A is shown in Figure 4.8.

Figure 4.8

4a.5 RUNNING THE SIMULATION

Once all of the circuit data has been entered, and the case compiled, the simulation is ready to run.

The case can be loaded into RunTime using the Fileï>Open option from the RunTime main menu. Alternatively, the case can be opened using the [icon] icon from the RunTime toolbar.

During the simulation, signals of interest are the burden current, flux and magnetizing current. The three signals can be put on the same plot, but each signal can be put on a different graph. To create a plot with three different graphs,

Sselect the create plot icon [icon] from the RunTime toolbar

Alternatively, the Add Plot window can be invoked using the Create menu in the RunTime main menu. A Create menu is also available by clicking the right mouse button on the RunTime page background.

Sselect the arrow up ▲ to increase the Number of Graphs to 3
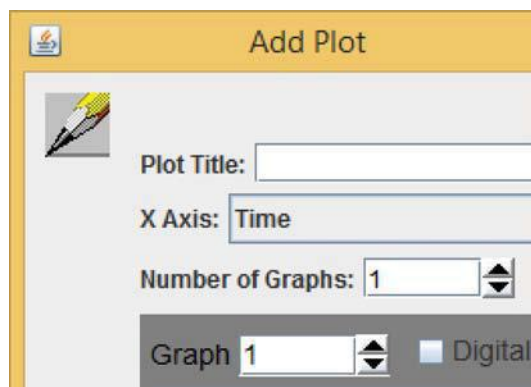
      Sset the Graph number to 1

      Sselect the signal CT flux to add to Graph #1

      Sset the Graph number to 2

      Sselect the signal CT magnetizing current to add to Graph

      #2 Sset the Graph number to 3

      Sselect the signal CT burden current to add to Graph #3

      Sselect the Add Plot button at the bottom of the window

The Bï H loop can be monitored in RunTime using the XïY plotting feature. By default, time is plotted on the xïaxis. A different signal can be chosen to plot on the xïaxis. To create an XïY plot,

      Sselect the create plot icon ![icon] from the RunTime toolbar.

      Sselect the Choose Signal box for the xïaxis

      Sselect the CT magnetizing current to be plotted on the xïaxis

      Sselect the CT flux to be plotted on the yïaxis

To operate the controller, the controls pushbutton must be created. This button is used to initiate the fault/breaker control sequence. To create a pushbutton,

      Sselect the create button icon ![icon] from the RunTime toolbar

      Sgo to CTLs/Inputs folder

      Sselect the name assigned to the pushbutton

If desired, sliders can be created to modify the fault and breaker duration. For simulation results shown, the initial values entered in Draft are used for the pulse durations.

The RunTime plot duration which is referred to as the finish time, is set to 0.4 secs. This value can be entered in the RunTime Caseï>Options menu.

After the plots and pushbuttons have been created in RunTime, the simulation can be started by selecting the play icon ![icon] from the RunTime toolbar. To collect steady state data, the update plots icon ![icon] can be selected. To initiate the fault/breaker sequence, press the pushbutton. Simulation results are shown in Figures 4.9 and 4.10

Referring to Figure 4.9, after reclose, the flux is offset and Figure 4.10 shows the CT BïHloop is asymmetrical. This is due to the trapped flux or remanent flux and causes distortion in the burden current. This offset will remain until the core is energized in the other direction (ie. follow the path cïd of the BïH loop).

Current transformers can continue to operate with trapped flux in the core. The cause of concern is if another fault occurs on the system, the CT can saturate prematurely.
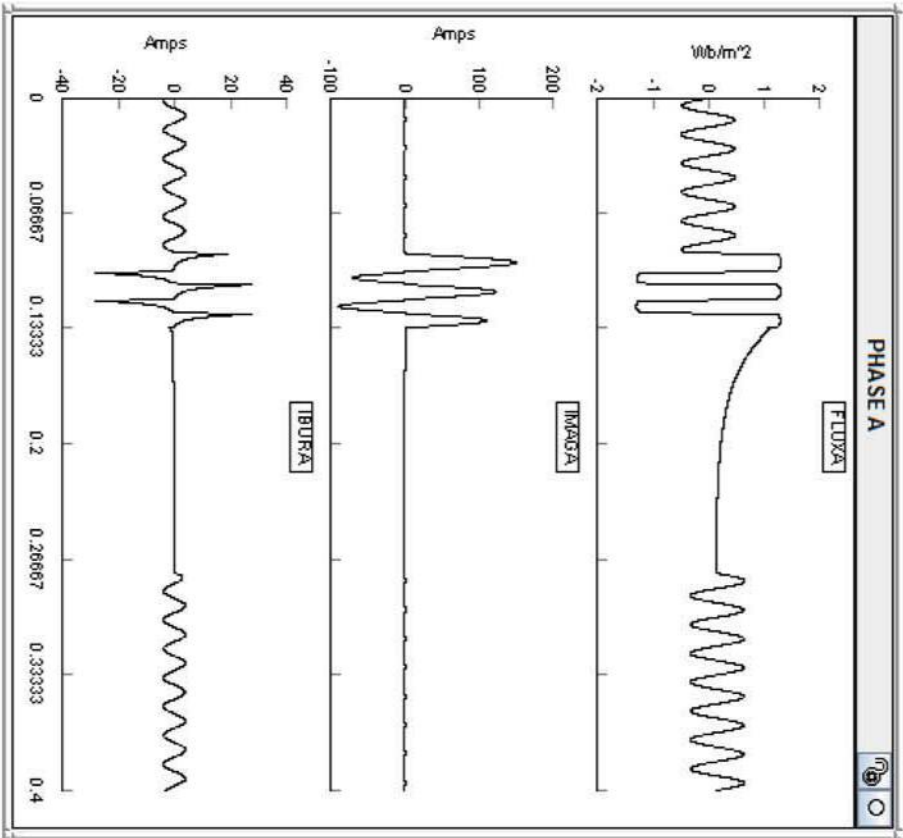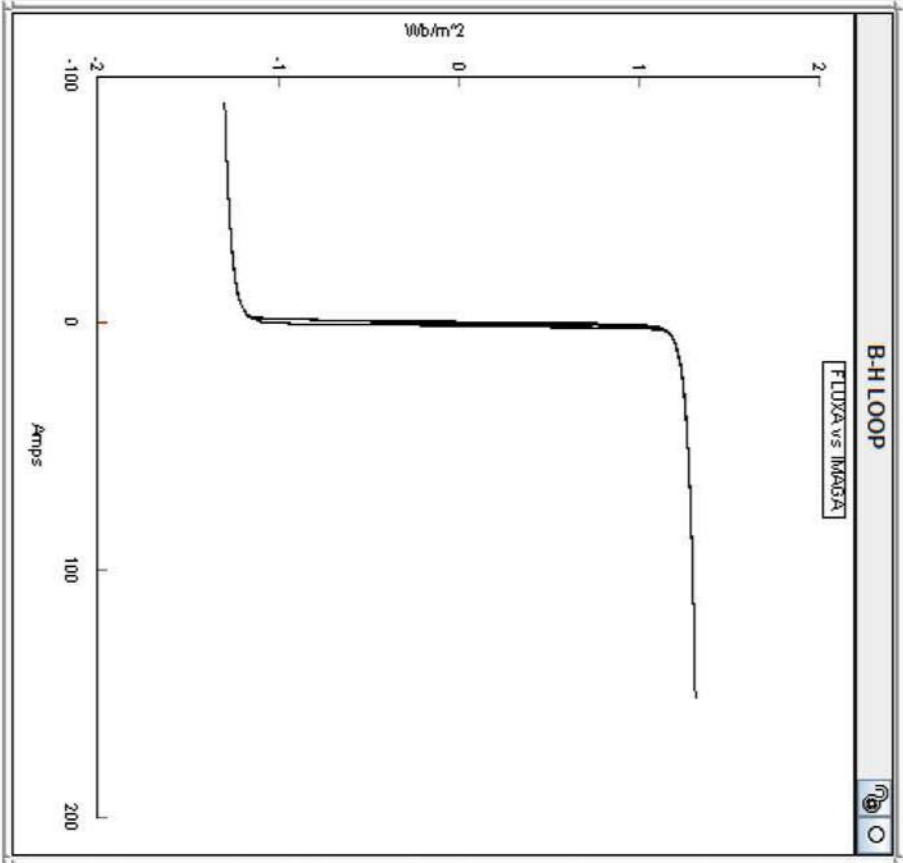
Current Transformer

Figure 4.9

Figure 4.10

4a.6 REFERENCES

1. W.L.A. Neves and H.W. Dommel, "On Modelling Iron Core NonLinearities", I.E.E.E Trans. on Power Systems, Vol 8, No.2, May 1993, pp. 417ï423.

2. Working Group Cï5 of the Systems Protection Subcommittee of the IEEE Power System Relaying Committee "Mathematical Models for Current, Voltage and Coupling Capacitor Voltage Transformers", I.E.E.E Trans. on Power Delivery, Vol 15, No.1, January 2000, pp. 62ï72.