Predicting Current Differential Relay Tripping and Targeting when Testing at Final Settings

John Horak
Basler Electric Company

All relay manufacturers have test routines for their transformer differential relays, but these routines are based upon some factory-selected settings, typically for a basic Wye-Wye transformer configuration. Many wish to test the relay at the final in-use settings that include the common delta-wye transformer compensation techniques available in modern transformer differential relays. However, the compensation, in conjunction with the effects of slope settings, minimum operate settings, effective through current algorithms, tap effects, acceptable relay tolerances, having access to only a 3 phase current source (compared to the 6 currents in a 3 phase transformer), etc., combine to make trip testing a surprisingly complicated issue. To assist people testing at final settings, the paper will discuss some of the issues involved with setting a transformer differential relay, and it will then present a Microsoft Excel™ spreadsheet that emulates the operation of Basler current differential relays and predicts when targeting will occur for user defined settings and current injection. This spreadsheet shows relay response to arbitrary currents on all phases and multiple windings, but likely the more useful part of the spreadsheet is that the sheets show how to test the Basler transformer differential relays at final settings with a single three phase test set, using only two of the test set's current sources.

Basic Concepts

The current balance that a transformer differential relay monitors is actually is a matter of flux balance: The flux in each transformer core leg (leg A, B, and C, figure 1) that is due to load current (note we said load current, not excitation current) sums to 0. This concept is only approximately true because:

a) There will be some excitation current that flows into one winding that is not matched by current in the other windings on that core leg, and
b) There will be some coupling between core legs. The strong tendency is for load-induced flux to sum to zero on a per leg basis, but in actuality, load flux sums to zero in the transformer as a whole. There is some capability in the transformer for leg-leg current transformation, which tends toward operation of a differential relay. This is discussed in more detail in reference 1.

Both of these effects are small in normal operation. Hence, in figure 1, the flux due to load current in W_1 and W_4 is approximately equal and opposite, so that the flux due to load sums to zero on that leg. Since flux is directly proportionate to coil turns ratio, the balance in load current is inversely proportionate to coil turns ratio.

In figure 1, note the use of two types of bushing/terminal designations. The terms H1/2/3 and X1/2/3 are North American terminology, and 1U/V/W, 2U/V/W is a more international terminology. Note also that a "Winding" does not refer to an individual coil, but to a set of three A, B, and C coils at a common voltage level.

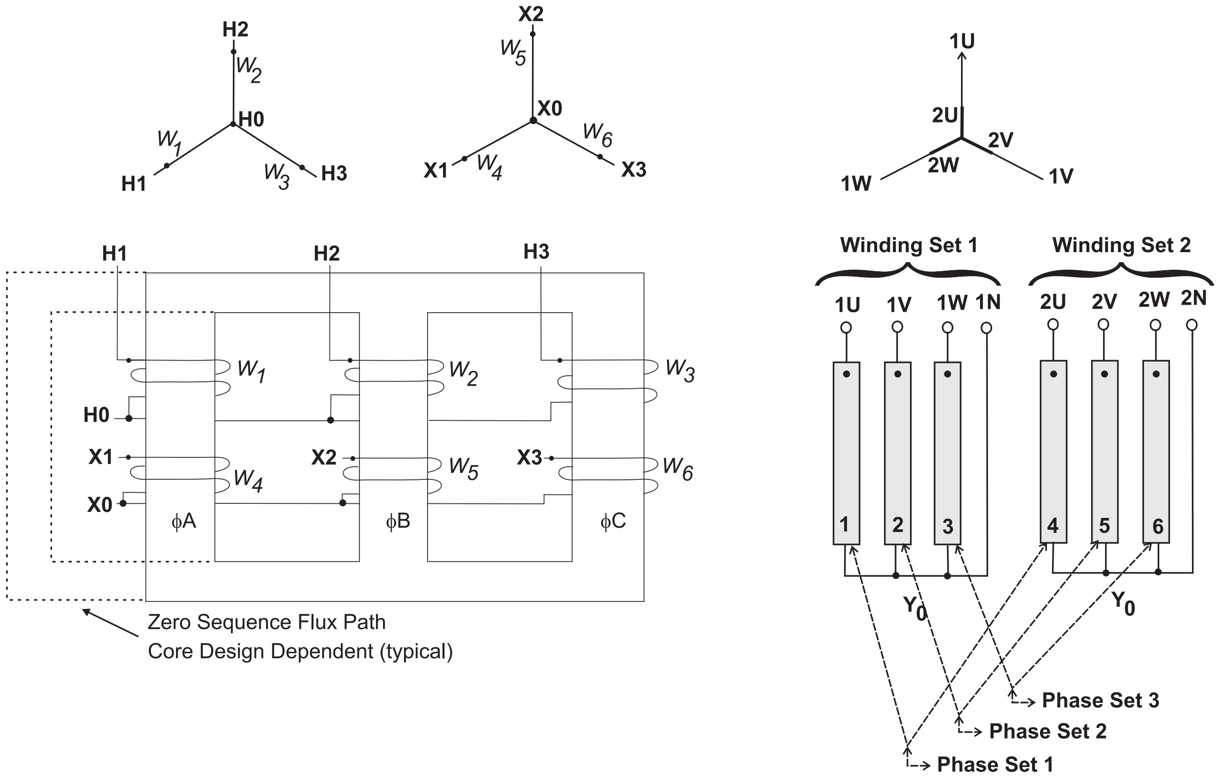


Figure 1 - Basic Transformer Representation

The most obvious current differential application to analyze is the case where the two currents are equal in normal conditions. Figure 2 shows the basic concept. Normally, current in equals current out (after per-unitizing via the tap circuit) but, given a fault, the Operate leg of the transformer sees the difference current and, if it rises beyond a certain level, the relay trips. The figure has insufficient detail to show some other aspects of the transformer differential relay:

- The figure hints at the effect of taps, but without more details on internal wiring, it does not show how two different currents are per-unitized to a quantity called “Multiples of Tap” (MOT) and then compared.
- The figure does not show how the two restraints are looked at together by the relay to find one net effective restraint.
- The figure does not show the “percentage restraint” effect. Only a percentage of the restraint current is compared to the operate current. If the current in the operate leg rises above a certain percentage of the restraint leg, the relay trips.
- The figure does not show the minimum operate effect. Current in the operate leg has to rise above a base current level in MOT before a trip will occur.
- The figure does not show how the relay senses a transformer energization inrush condition and then blocks tripping. This is normally done via detection of high harmonics (especially 2nd and maybe 5th) in the operate leg.

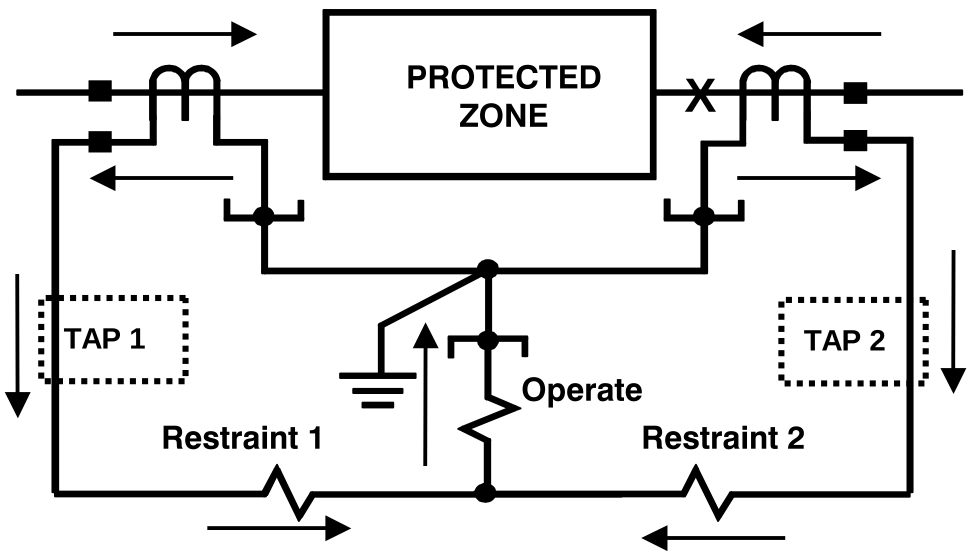


Figure 2 - Basic Differential Relay Concept

Virtually every relay has its own variation of how the effective restraint and operate current is determined and how this is used to determine when to trip. The Basler BE1-87T uses the maximum of |Restraint 1| and |Restraint 2| (note that the vertical bars," |<current value> |", around a term signifies "magnitude"), which is then compared to |Operate|. The Basler BE1-CDS line gives the user the option of using either the maximum or the average of |Restraint 1| and |Restraint 2| for the restraint, though using the maximum is encouraged. Both relays use fundamental frequency data for these quantities.

The current in the operate leg typically must be above some minimum operate value. The percentage of the restraint that is compared to the operate quantity is referred to as the slope. A common way that the trip vs. non-trip zone is described is shown in figure 3, taken from reference 2, the BE1-87T Instruction Manual (I/M).

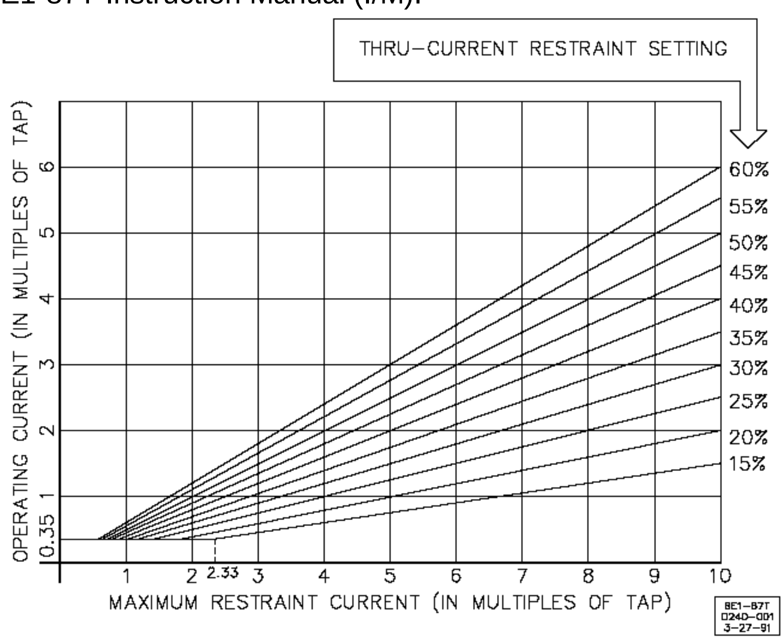


Figure 3 - Operate vs. Restraint and Minimum Operate, BE1-87T

Transformer and CT Delta Connections

For this paper we will examine the common D_{AB} - Wye and D_{AC} - Wye transformer configurations, figures 4, 5, and 6, that give either a $+30^0$ or -30^0 phase shift of positive sequence voltages and currents. There are actually many other ways to configure a wye or delta or even zig-zag that give other “around the clock” phase shifts. See Reference 1 (“*Three Phase Transformer Winding Configurations and Differential Relay Compensation”*) for a more advanced discussion of compensation for myriad possible transformer configurations.

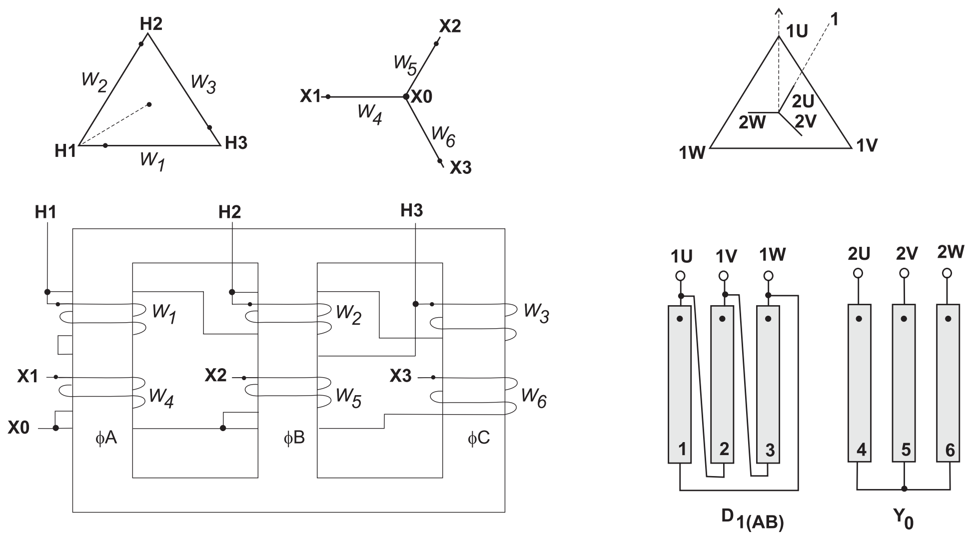


Figure 4 - $D_{AB}Y$ (Dy1))

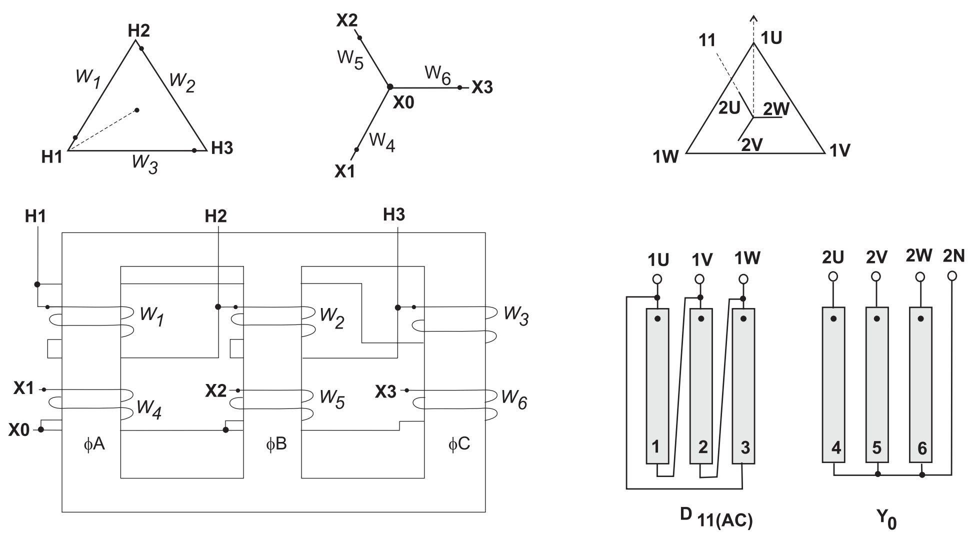


Figure 5 - $D_{AC}Y$ (Dy11)

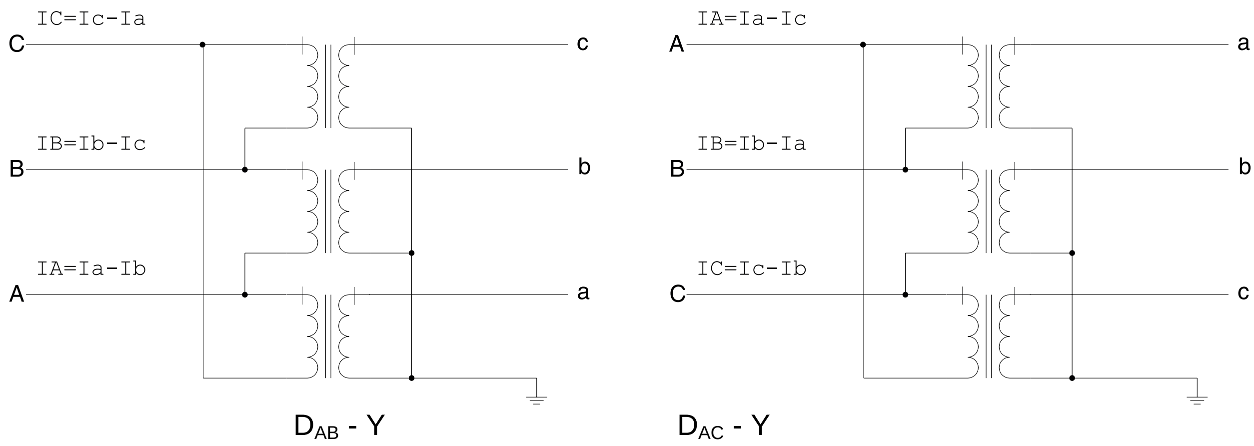


Figure 6 - D_{AB} vs. D_{AC} Transformer Connections (from Ref. 3)

A relay monitoring the current in the lines outside the transformer delta is actually seeing the difference of the current in two coils on the transformer. For instance, in figure 6, a CT on the phase A line outside the D_{AB} winding sees Ia-Ib, where Ia and Ib are the current in the coils of the transformer. The CTs on the wye side, however, sense the current in only one coil of the transformer. The historical practice, especially before the era of the BE1-87T and modern numeric relays, has been to compensate for the effects of the D_{AB} or D_{AC} transformer connections by connecting CTs on the opposite winding in the same D_{AB} or D_{AC} fashion, seen in figure 7.

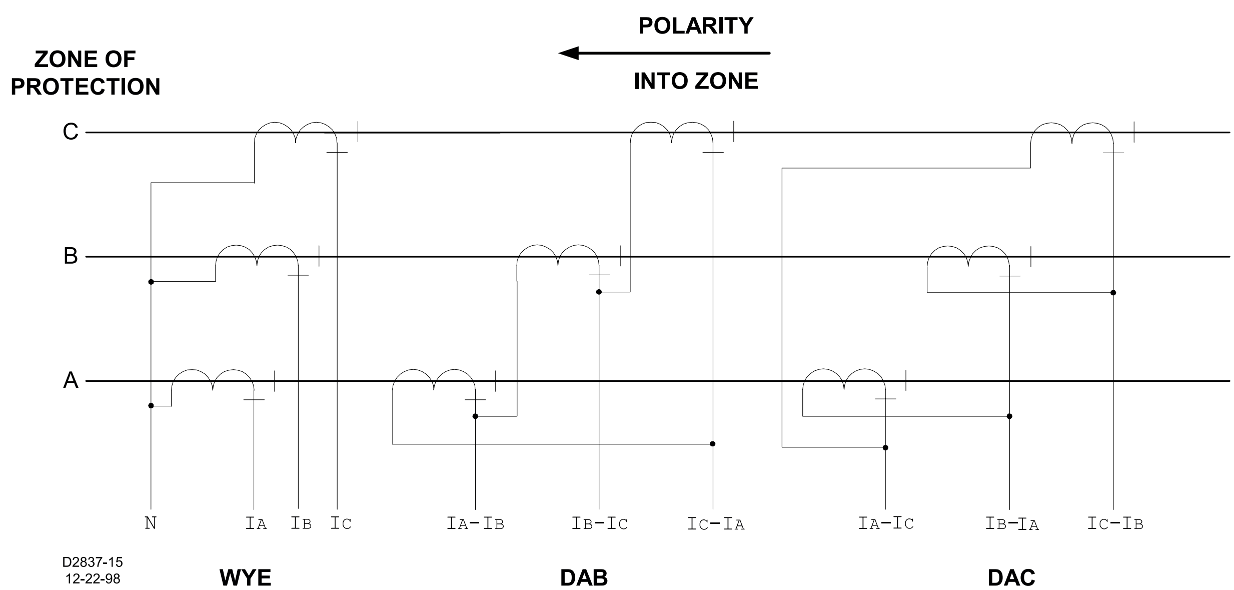


Figure 7 - D_{AB} vs. D_{AC} CT Connections

An example of using CT connections to create delta compensation is seen in figure 8. Due to transformer delta connections, the A phase line on the left side contains the transformer current Ia - Ib. To compensate, the CTs on the right are also connected in delta in such a way that the two inputs to the top BE1-87T-1 are both seeing “Ia-Ib”. The two currents will be of different magnitude, but this will be compensated for via the transformer differential relay tap circuitry, described later.

Figure 8 begins to show the issues that will arise with targeting. Each BE1-87T element in the diagram is seeing current in two transformer coils, so it may be unclear which coil in the transformer has faulted based merely on relay target information. If the CTs are both connected in wye and the delta compensation is brought into the relay, the confusing targeting still exists and also complicates relay testing.

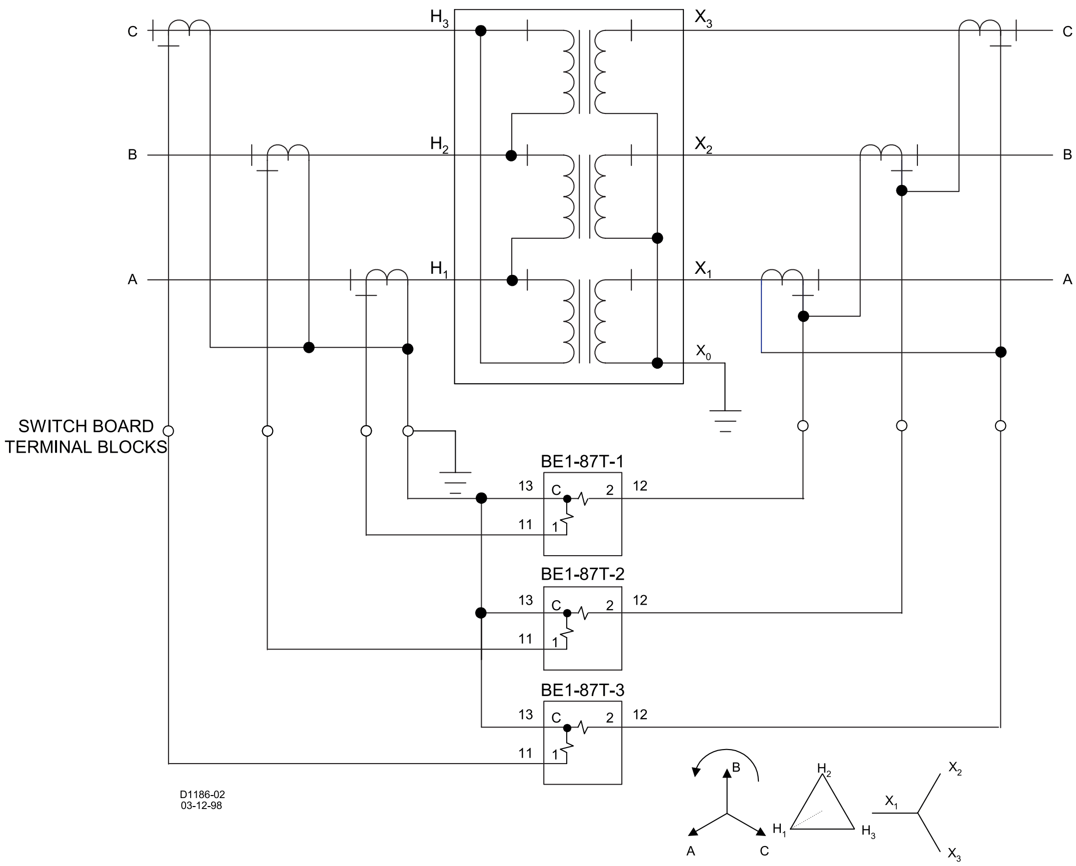


Figure 8 - Transformer Delta Compensation Using Delta CTs

Just Say No to Delta CTs

Modern practice is to avoid connecting CTs in delta and to use relays that can perform the delta compensation internally. Delta connections cause distortions and loss of information on line currents:

- Zero sequence current is filtered out, so ground fault current cannot be measured and ground overcurrent protection cannot be implemented.
- Individual line currents are unknown and cannot be calculated if there was any lost zero sequence current flow in the line currents.
- Positive and negative sequence currents are shifted by +/-30^0 respectively.
- If there is any phase-ground zero sequence load flow, single phase power flow can only be estimated, and total three phase power will be correct

Some people also dislike delta CTs because, during steady state balanced load flow when CTs are in delta, the line current is increased by a sqrt(3) factor over the what is in the CT secondaries, which means higher effective CT burden.

Basler Electric Differential Relays and Theory of Operation

Basler Electric manufactures two designs for transformer differential relays, the analog design BE1-87T line, and the numeric design BE1-CDS220 line. Instruction manuals, references 2, 3, and 4 should be the best resources on what these relays can do. The theory of each relay is similar: All are based upon the concept that flux associated with load current in each leg of Figure 1 sums to essentially 0 and, hence, after turns ratio compensation, the current in the phase coil set on each transformer leg sums to 0.

1) BE1-87T

This relay is an analog design relay developed in the late 1980s, utilizing op-amps, capacitors/inductor/resistor filtering schemes, analog comparators, and basic AND/OR type logic chips. The relay has no microprocessor. It is available as:

- Single phase, with inputs for two to five single phase windings
- Three phase, with inputs for two or three three-phase windings

The single phase version is more straightforward than the other relays, because it lacks the confusion factor of internal delta compensation. This paper and the associated spreadsheet directly address testing only the three phase version of the BE1-87T. The single phase version can be emulated in the spreadsheet by setting the three phase relay to a “Wye-Wye” compensation mode.

The three phase version of the relay has internal compensation jumpers that change the inputs to the relay’s op-amp circuits in a fashion that emulates the effect of connecting CTs in delta. See Reference 5 (“BE1-87T, 3 Phase Versions: Understanding Targets and Testing the Internal Phase Shifting Network”) for a description of the compensation technique used in the BE1-87T.

2) BE1-CDS

The BE1-CDS 2x0 relays are numeric transformer differential relays that do the work of the three phase BE1-87T plus many more functions. Besides the 87Phase function, the relays also perform an 87Neutral Differential (87ND) function and a suite of 50/51Ph, Negative Sequence, and Neutral / Ground overcurrent functions. There is also programmable logic, event reporting, remote communication, etc. The relays use numeric techniques and fast sampling of the current waveform. The incoming current is passed through an analog filter to remove high frequency distortions, the waveform is then sampled at 144 samples/cycle, another level of digital filtering is utilized, and then finally 24 samples per cycle are utilized in a Discrete Fourier Transform (DFT) to extract the magnitude and angle of the fundamental frequency, 2^{nd}, and 5^{th} harmonic of the current. The relays perform the transformer and CT compensation via mathematical functions of the relay microprocessor.

There are two basic versions of this CDS relay line:

- CDS220 - Three phase, two windings, and ground current functions
- CDS240 - As above but two to four windings, voltage inputs, and miscellaneous advanced features

The CDS220 is designed for transformers with two winding sets, and the transformer connection compensation techniques in the relay are aimed at the common delta-wye transformers with +/- 30^0 phase shifts, as well as delta-delta and wye-wye transformers, and delta connected CTs. The CDS240 has the logic to easily handle a huge variety of possible transformer and CT configurations that CDS220 might handle a bit clumsily. The listing of possible transformer configurations may be found in Reference 1.

Theory of Operation of the BE1-87T

Even if one is not using the BE1-87T, it is worthwhile to understand it, since it is the basis for the design of the CDS line, and it shares many basic design concepts with many other relays on the market.

The three phase BE1-87T allows CTs to be connected in wye by compensating for delta connections in a fashion that emulates the CT connections via a set of op-amp circuits. An inspection of figure 9, taken from Reference 5, shows how the BE1-87T tap circuits and compensation circuit jumpers work. Note that the currents come into the relay via a current transformer with an adjustable secondary resistance. This resistance determines the tap of the relay. For instance, assume a 5,000:1 CT with a 10 secondary ohm burden. If 5A comes into the relay, then 10mV is developed across the resistor. The tap setting of the relay is basically a change in the resistance, so as to make a variety of currents give the same internal voltage level and, hence, allow two different currents to give the same internal signal.

An inspection of the jumper circuit will show that, if the jumpers are in the Δ2 position, the current into the restraint and operate circuits are I_A-I_B, I_B-I_C, and I_C-I_A and hence are emulating a D_{AB} connection of the CTs. By changing the position of the jumper, the middle set of op amps can have an output that emulates either a Wye (Y jumper position), a D_{AC} (Δ1 jumper position), or a D_{AB} (Δ2 jumper position) CT connection.

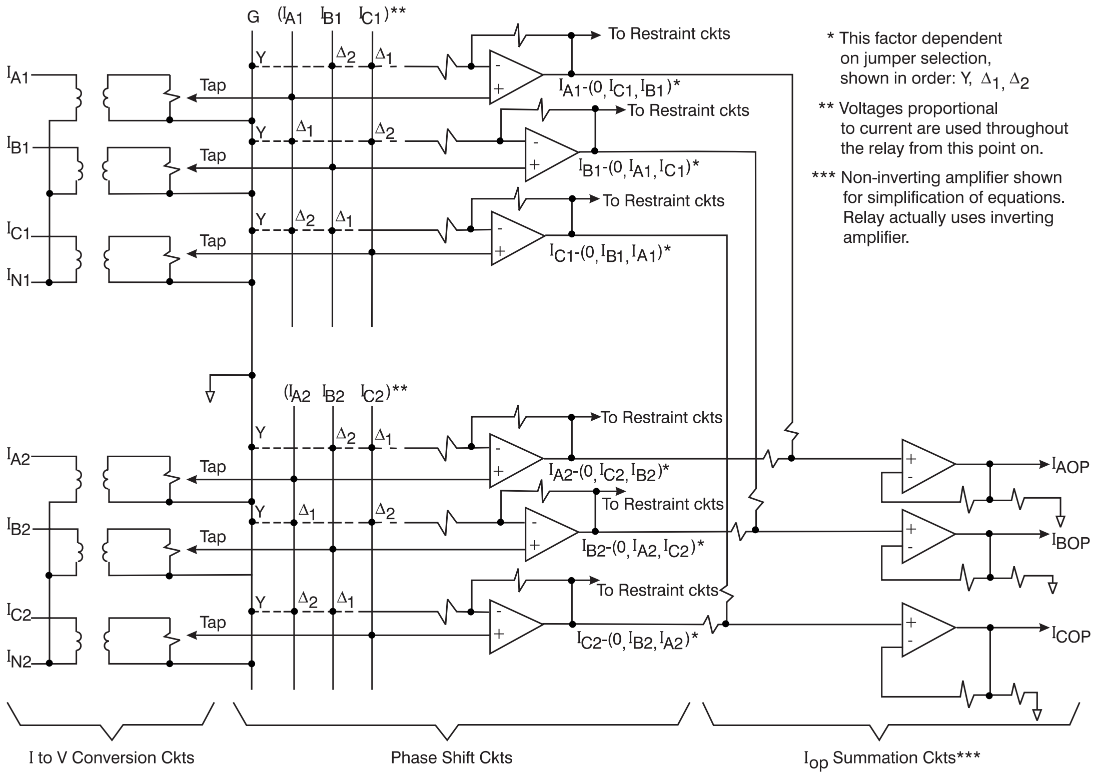


Figure 9 - The Delta Compensation Schemes of the BE1-87T

The relay has 3 comparators for current balance; let us call them comparators A, B, and C. The three comparators look at:

$$
\begin{aligned}
\text{Comparator A}: &\quad I'_{A1} \quad \text{vs.} \quad I'_{A2} \\
\text{Comparator B}: &\quad I'_{B1} \quad \text{vs.} \quad I'_{B2} \\
\text{Comparator C}: &\quad I'_{C1} \quad \text{vs.} \quad I'_{C2}
\end{aligned}
\qquad (1)
$$

The 6 currents monitored by the three comparators is dependent on the position of the Wye/ Δ1/Δ2 jumpers:

$$
\begin{aligned}
I'_{A1} &= \frac{I_{A1} - [0, I_{C1}, I_{B1}]}{\text{Tap 1}} \cdot K \qquad & I'_{A2} &= \frac{I_{A2} - [0, I_{C2}, I_{B2}]}{\text{Tap 2}} \cdot K \\
I'_{B1} &= \frac{I_{A1} - [0, I_{A1}, I_{C1}]}{\text{Tap 1}} \cdot K \qquad & I'_{B2} &= \frac{I_{A2} - [0, I_{A2}, I_{C2}]}{\text{Tap 2}} \cdot K \\
I'_{C1} &= \frac{I_{A1} - [0, I_{B1}, I_{A1}]}{\text{Tap 1}} \cdot K \qquad & I'_{C2} &= \frac{I_{A2} - [0, I_{B2}, I_{A2}]}{\text{Tap 2}} \cdot K
\end{aligned}
\qquad (2)
$$

where the part in brackets is representative of the value that would be used if the jumper were in the Wye/ Δ1/Δ2 position, respectively, and the K factor represents a constant internal to the relay that represents the “current-to-equivalent voltage” conversion factor used for the op amp circuits. It should be noted that, for balanced three phase currents, the equations of (2) result in a increase in effective current in just the same fashion as connecting CTs in delta (e.g., for balanced 3 phase current, there is a sqrt(3) increase in current). This factor is compensated for by appropriate setting of the taps, discussed below.

Multiples of Tap (MOT)
The engineer/technician does not have access to the relay's internal electronic signals, so does not need to be informed of the value of K in equation 2. If we assume that K=1, then all of the current quantities in the analysis of relay response are effectively in "multiples of tap" (MOT). The BE1-87T I/M and the Microsoft Excel spreadsheet associated with this paper present all data based upon the concept that K=1 and, hence, is in terms of multiples of tap.

Restraint Current
The restraint current used by the comparators is:

$$\begin{aligned}
&\text{Comparator A Max Restraint:} \quad \text{Maximum of } \left(\left|I'_{A1}\right| \text{ or } \left|I'_{A2}\right|\right)\\
&\text{Comparator B Max Restraint:} \quad \text{Maximum of } \left(\left|I'_{B1}\right| \text{ or } \left|I'_{B2}\right|\right) \qquad (3)\\
&\text{Comparator C Max Restraint:} \quad \text{Maximum of } \left(\left|I'_{C1}\right| \text{ or } \left|I'_{C2}\right|\right)
\end{aligned}$$

This restraint is modified by the "% Slope" setting to find an effective restraint:

$$\begin{aligned}
&\text{Comparator A Effective Restraint:} \quad \text{\% Slope x Maximum of } \left(\left|I'_{A1}\right| \text{ or } \left|I'_{A2}\right|\right)\\
&\text{Comparator B Effective Restraint:} \quad \text{\% Slope x Maximum of } \left(\left|I'_{B1}\right| \text{ or } \left|I'_{B2}\right|\right) \qquad (4)\\
&\text{Comparator C Effective Restraint:} \quad \text{\% Slope x Maximum of } \left(\left|I'_{C1}\right| \text{ or } \left|I'_{C2}\right|\right)
\end{aligned}$$

The slope setting is one means for the user to desensitize the relay; the higher the restraint current, the higher the error current must be for the relay to trip. For lower through current, the relay will be more sensitive to internal faults.

Operate Current
The operate current is

$$\begin{aligned}
&\text{Comparator A Operate:} \quad \left|\overrightarrow{I'_{A1} + I'_{A2}}\right|\\
&\text{Comparator B Operate:} \quad \left|\overrightarrow{I'_{B1} + I'_{B2}}\right| \qquad (5)\\
&\text{Comparator C Operate:} \quad \left|\overrightarrow{I'_{C1} + I'_{C2}}\right|
\end{aligned}$$

The arrow above the summation indicates phasor math is used when one is comparing fundamental frequency phasor data. However, the relay does not actually utilize phasors but works with instantaneous values filtered to respond mainly to fundamental frequency data.

Minimum Pickup
The relay will not trip unless the results of equation 5 are above some minimum value. If we assume K in equation (2) is 1 and, therefore, think in terms of Multiples of Tap, the minimum operate quantity is 0.35 MOT. The 0.35 factor is adjustable but requires a special calibration routine that is not widely publicized. To change it, the user needs to either return the relay to the factory or obtain a copy of a special field calibration routine and an "extender card" from Basler.

Trip Decision Logic
The relay trips when the operate quantity is greater than the effective restraint, and the operate quantity is above the "minimum pickup" value. Hence, the relay trips when:

Comparator A Operate > Comparator A Effective Restraint
AND Comparator A Operate > 0.35 (or other Min PU setting)
OR
Comparator B Operate > Comparator B Effective Restraint
AND Comparator B Operate > 0.35 (or other Min PU setting) (6)
OR
Comparator C Operate > Comparator C Effective Restraint
AND Comparator C Operate > 0.35 (or other Min PU setting)

A caveat is that tripping could be blocked for high harmonic content, indicating inrush or high excitation current. These harmonic blocking schemes do not affect understanding of the tripping of the relay during normal testing and will not be covered further herein. See the instruction manuals for additional information on harmonic blocking.

Unrestrained Differential 87U
The unrestrained Differential, 87U, is setting aimed at detecting high magnitude internal faults that trip high speed and defeat any harmonic blocking. The basic concept is that, if the operate current rises above a set level, this is a level that could not be explained by CT error or inrush. If this level is met, harmonic blocking is ignored, and the relay trips. The unrestrained trip function will not be covered further in this paper.

Tap Settings

Determining the tap settings for the BE1-87T can be confusing. The largest sources of confusion are associated with a) proper selection of the Wye/ Δ1/Δ2, jumpers, and b) proper selection of the tap. The tap is confusing due to issues on how to handle the sqrt(3) factor that arises due to delta CT connections. A mistake on the order of a sqrt(3) factor can be missed for an extended period. Transformer differential relays are not highly sensitive devices, and people who have set taps incorrectly by a sqrt(3) factor have had the transformer in service for months or even over a year before a major load swing or external fault caused enough current for the relay to trip.

Determining taps is, in concept, fairly easy:

1. Find full load current of the transformer. Assume balanced 3 phase loads.
2. Find the current that will be at the relay terminals for this load current, including any "sqrt(3)" factors introduced by CTs connected in delta.
3. If a relay input will utilize the internal delta compensation jumpers, multiply the relay current on that input by the sqrt(3) factor.
4. Set the taps to these currents.

There are a few tricks, though:

- There are some complications when one examines the performance of the CTs for a high magnitude external fault and wishes to determine if some marginal CTs or high CT burden is at risk of causing the CTs to collapse, causing the relay to see an external fault as an internal fault and trip. If the CT is insufficiently robust, this may affect the relay slope setting.

- There are also issues with CT ratio selection and associated CT saturation point that affect the recommended setting for the unrestrained differential, 87U.
- Any set of taps can be utilized, as long as the tap ratio is the same as the current ratio. However, the big issue is that adjusting the taps up and down as a whole effectively changes the minimum current required for tripping.
- The % slope setting has not been covered, but it is basically a decision based on assumed CT performance, how well one knows transformer turns ratio, and how well one expects the transformer to act ideally as 3 independent perfect single phase transformers (refer back to Basic Concepts, item b).

BE1-87T Microsoft Excel™ Settings Calculation Spreadsheet

The setting of taps is discussed in the instruction manuals, but there is a spreadsheet, Reference 6, available to assist in setting the relay. See figure 10. The screenshot is the data entry sheet; a second sheet displays calculated values and recommended taps and slope settings. Further discussion of using this spreadsheet will not be considered herein. It will be left to the reader to obtain a copy of this spreadsheet and work with it, which is likely the only effective way to learn how to apply it.

	A	B	C	D
1	**87T SETTINGS BASED ON PROCEDURE TWO**			
2	**Without Fault Calculations**			
3	This version of the 87T settings calculation workbook template uses fault current magnitudes calculated			
4	in your own fault study and entered on the data sheet for CT performance calculations. You do not need			
5	the Analysis Toolpak Add-In installed in Excel to use this version of the template.			
6				
7	Fields highlighted in yellow are for data entry.			
8				
9	SPECIFICATIONS	VALUE	INPUT 1	INPUT 2
10	**SYSTEM**			
11	KV_{LL} (BASE)		69	12.47
12				
13	3PH, input 2 side fault, EXTERNAL (F1)		1916	10603
14	3PH, input 1 side fault, EXTERNAL (F2)		0	0
15	PH-G, input 2 side fault, EXTERNAL (F1)		1171	11231
16	PH-G, input 1 side fault, EXTERNAL (F2)		0	0
17	**TRANSFORMER**			
18	WINDING CONFIGURATION (D OR Y)		d	y
19	MVA (self cooled - OA)	12		
20	MVA (forced cooled - FA)	20		
21	MVA (expected max load)	20		
22				
23	LTC range +/- %	10		
24				
25	**CTs**			
26	PRI CURRENT RATING (FULL WINDING)		600	1200
27	PRI CURRENT RATING (TAPPED)		300	800
28	SEC CURRENT RATING		5	5
29	CT ACCURACY CLASS (volts @ 20X In)		400	800
30	CT CONNECTION (D or Y)		y	y
31	ONE WAY LEAD RESISTANCE (Ohms)		0.7	0.7
32				

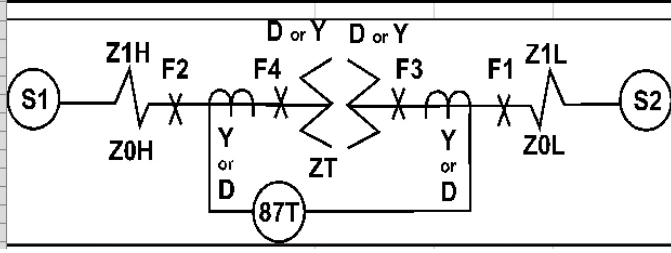


Figure 10 - 87T Settings Sheet

Theory of Operation of the BE1-CDS relays

The BE1-CDS relays operate on a very similar concept to the BE1-87T and, in fact, Basler somewhat mimicked the BE1-87T in much of the design of the BE1-CDS. However, there are some considerable differences, too.

The op-amp circuits used in the BE1-87T are replaced by mathematics in the BE1-CDS. As soon as currents are converted to a phasor equivalent number, the relay can multiply or divide to create scaling factors that do the work of the resistor based tap circuits of the BE1-87T, and the relay can add or subtract to do the work of the delta compensation op amp circuits. There are some differences in the CDS line, though, to be aware of:

Sqrt(3) factor for Delta Compensation.

The BE1-CDS tap settings on windings with delta compensation are typically lower than the BE1-87T tap settings by a factor of sqrt(3) for the same transformer configuration. When delta compensation is in use, during balanced 3 phase current conditions, the lines external to a delta have more current by a factor of sqrt(3) than the windings inside the delta. Users of the BE1-87T have to be aware that this sqrt(3) current buildup also occurs in the delta compensation circuit in the relay, and taps must be set accordingly. However, in the BE1-CDS the relay automatically multiplies the sensed current by 1/sqrt(3) when delta compensation is in effect, which means the user sets the relay taps based upon the balanced load current at the relay terminals and, hence, ignores the sqrt(3) factor found in the BE1-87T delta compensation jumpers.

Minimum Pickup

The BE1-CDS allows users to easily change the minimum pickup. It is settable over a range of 0.1 to 1.0 MOT.

Restraint based on Average or Maximum

The BE1-CDS allows the user to have the relay calculate restraint based upon the average of the restraints rather than the maximum of the restraints. Basler recommends that customers use the maximum of the restraints but has given the option to use average. If average restraint is selected, equation (3) above becomes, for a two input relay:

$$\begin{aligned} &\text{Comparator A Avg Restraint:} \quad \left(\left|I'_{A1}\right| + \left|I'_{A2}\right|\right)/2 \\ &\text{Comparator B Avg Restraint:} \quad \left(\left|I'_{B1}\right| + \left|I'_{B2}\right|\right)/2 \\ &\text{Comparator C Avg Restraint:} \quad \left(\left|I'_{C1}\right| + \left|I'_{C2}\right|\right)/2 \end{aligned} \qquad (7)$$

Neutral Differential Function (87ND)

The BE1-CDS has a feature to compare the current on the xfmr neutral (I_G input) to the ground current ($3I_0$) in the phase leads of one of the windings. (Since I_G is compared to $3I_0$ on only one of the windings, this typically works only on delta wye transformers.)

Automatic Tap Calculation

There is a feature in the relay to have the relay calculate tap settings from user-supplied transformer and CT information. This does not address side issues such as appropriate slope settings, determination if CTs will be overburdened during external faults, or the setting of the 87U.

Unrestrained Differential 87U

The operate quantity of the BE1-CDS relay, due to digital filtering techniques, responds strictly to fundamental quantity currents. The transient operate quantities associated with inrush and CT saturation tend to be harmonically rich, yet fault currents tend to be fundamental frequency issues. The high level of harmonic filtering blocks these CT transient saturation and inrush quantities from being seen well by the operate current measurements, so this allows BE1-CDS users to set the 87U to a lower level than the BE1-87T.

Overcurrent (50/51) elements

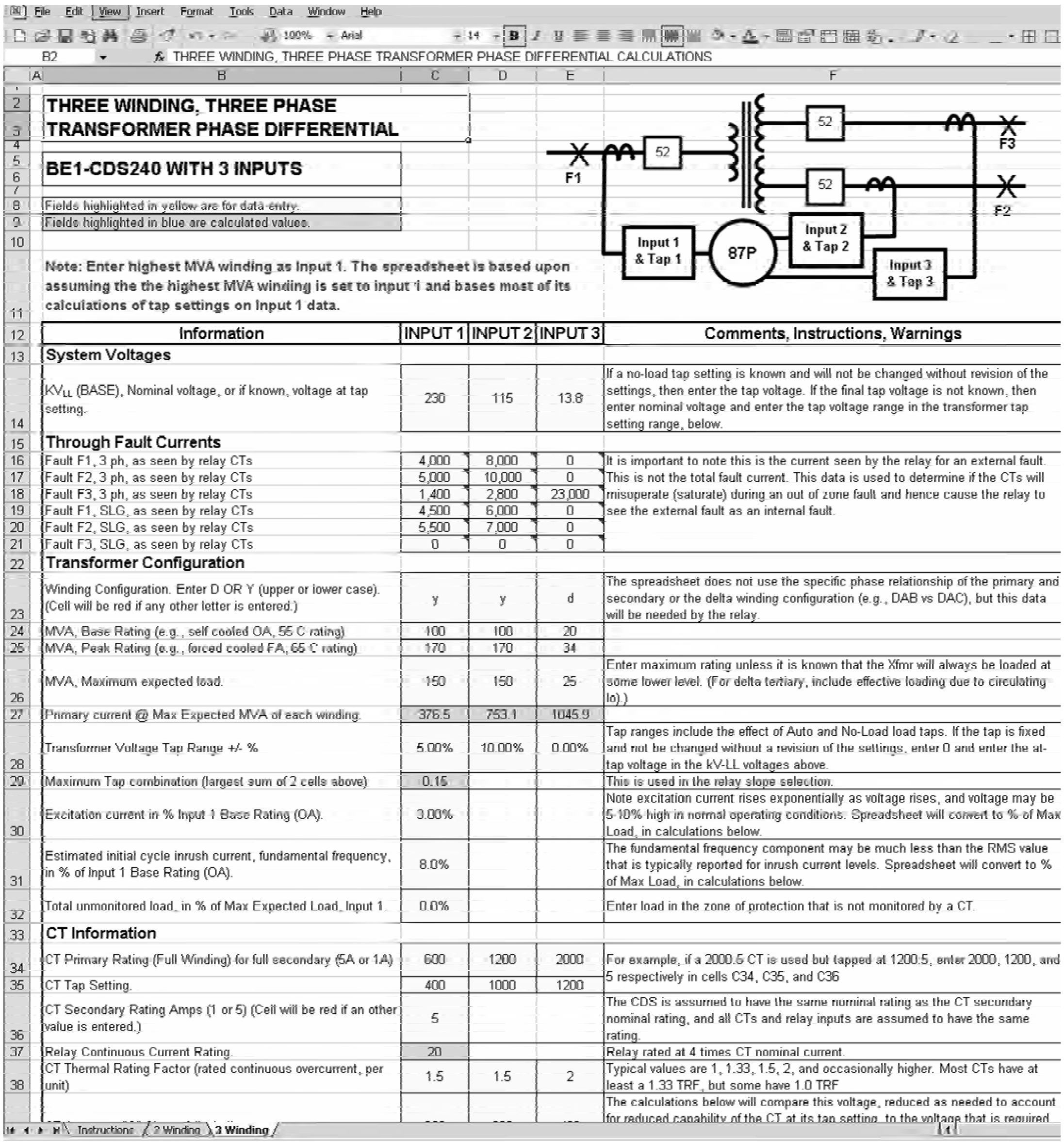
There is a variety of phase, neutral, and negative sequence overcurrent elements in the BE1-CDS line. These overcurrent elements can create issues when testing at final settings. They can create confusing trip paths, or even block some trip paths if users put in fault detector logic that supervises tripping.

User Programmable Logic

The programmable logic capabilities of the BE1-CDS relay can create a formidable problem when testing at final settings. Logic might be in place that under certain I/O conditions will block the relay from tripping the element that is being tested. Overcoming this logic by turning the logic off is tempting, but that is inherently a contradiction to the concept of testing at final settings.

BE1-CDS Microsoft Excel™ Settings Calculation Spreadsheet

Again, the setting of taps is discussed in the instruction manuals, but there is a spreadsheet available, reference 7, on the Basler web site to assist in setting the relay. A screen shot is shown in figure 11. Again, using the sheet in a real application will teach how it works better than any text description.



	Information	INPUT 1	INPUT 2	INPUT 3	Comments, Instructions, Warnings
13	**System Voltages**				
14	KV_{LL} (BASE), Nominal voltage, or if known, voltage at tap setting.	230	115	13.8	If a no-load tap setting is known and will not be changed without revision of the settings, then enter the tap voltage. If the final tap voltage is not known, then enter nominal voltage and enter the tap voltage range in the transformer tap setting range, below.
15	**Through Fault Currents**				
16	Fault F1, 3 ph, as seen by relay CTs	4,000	8,000	0	It is important to note this is the current seen by the relay for an external fault. This is not the total fault current. This data is used to determine if the CTs will misoperate (saturate) during an out of zone fault and hence cause the relay to see the external fault as an internal fault.
17	Fault F2, 3 ph, as seen by relay CTs	5,000	10,000	0	
18	Fault F3, 3 ph, as seen by relay CTs	1,400	2,800	23,000	
19	Fault F1, SLG, as seen by relay CTs	4,500	6,000	0	
20	Fault F2, SLG, as seen by relay CTs	5,500	7,000	0	
21	Fault F3, SLG, as seen by relay CTs	0	0	0	
22	**Transformer Configuration**				
23	Winding Configuration. Enter D OR Y (upper or lower case). (Cell will be red if any other letter is entered.)	y	y	d	The spreadsheet does not use the specific phase relationship of the primary and secondary or the delta winding configuration (e.g., DAB vs DAC), but this data will be needed by the relay.
24	MVA, Base Rating (e.g., self cooled OA, 55 C rating)	100	100	20	
25	MVA, Peak Rating (e.g., forced cooled FA, 65 C rating)	170	170	34	
26	MVA, Maximum expected load.	150	150	25	Enter maximum rating unless it is known that the Xfmr will always be loaded at some lower level. (For delta tertiary, include effective loading due to circulating Io).)
27	Primary current @ Max Expected MVA of each winding.	376.5	753.1	1045.9	
28	Transformer Voltage Tap Range +/- %	5.00%	10.00%	0.00%	Tap ranges include the effect of Auto and No-Load load taps. If the tap is fixed and not be changed without a revision of the settings, enter 0 and enter the at-tap voltage in the kV-LL voltages above.
29	Maximum Tap combination (largest sum of 2 cells above)	0.15			This is used in the relay slope selection.
30	Excitation current in % Input 1 Base Rating (OA).	3.00%			Note excitation current rises exponentially as voltage rises, and voltage may be 5-10% high in normal operating conditions. Spreadsheet will convert to % of Max Load, in calculations below.
31	Estimated initial cycle inrush current, fundamental frequency, in % of Input 1 Base Rating (OA).	8.0%			The fundamental frequency component may be much less than the RMS value that is typically reported for inrush current levels. Spreadsheet will convert to % of Max Load, in calculations below.
32	Total unmonitored load, in % of Max Expected Load, Input 1.	0.0%			Enter load in the zone of protection that is not monitored by a CT.
33	**CT Information**				
34	CT Primary Rating (Full Winding) for full secondary (5A or 1A)	600	1200	2000	For example, if a 2000:5 CT is used but tapped at 1200:5, enter 2000, 1200, and 5 respectively in cells C34, C35, and C36
35	CT Tap Setting.	400	1000	1200	
36	CT Secondary Rating Amps (1 or 5) (Cell will be red if an other value is entered.)	5			The CDS is assumed to have the same nominal rating as the CT secondary nominal rating, and all CTs and relay inputs are assumed to have the same rating.
37	Relay Continuous Current Rating.	20			Relay rated at 4 times CT nominal current.
38	CT Thermal Rating Factor (rated continuous overcurrent, per unit)	1.5	1.5	2	Typical values are 1, 1.33, 1.5, 2, and occasionally higher. Most CTs have at least a 1.33 TRF, but some have 1.0 TRF
					The calculations below will compare this voltage, reduced as needed to account for reduced capability of the CT at its tap setting, to the voltage that is required

Figure 11 - BE1-CDS220/230 Settings Spreadsheet

BE1-CDS BESTCOMS Setting Software

The BE1-CDS relays can be set via ASCII command sets, but a much more user friendly process is to utilize the Windows software, called "BESTCOMS™," that Basler provides free of charge; a screen shot is shown in figure 12. We will not review this software here, but anyone setting up and testing a BE1-CDS relay should not proceed without first obtaining a copy of this software.

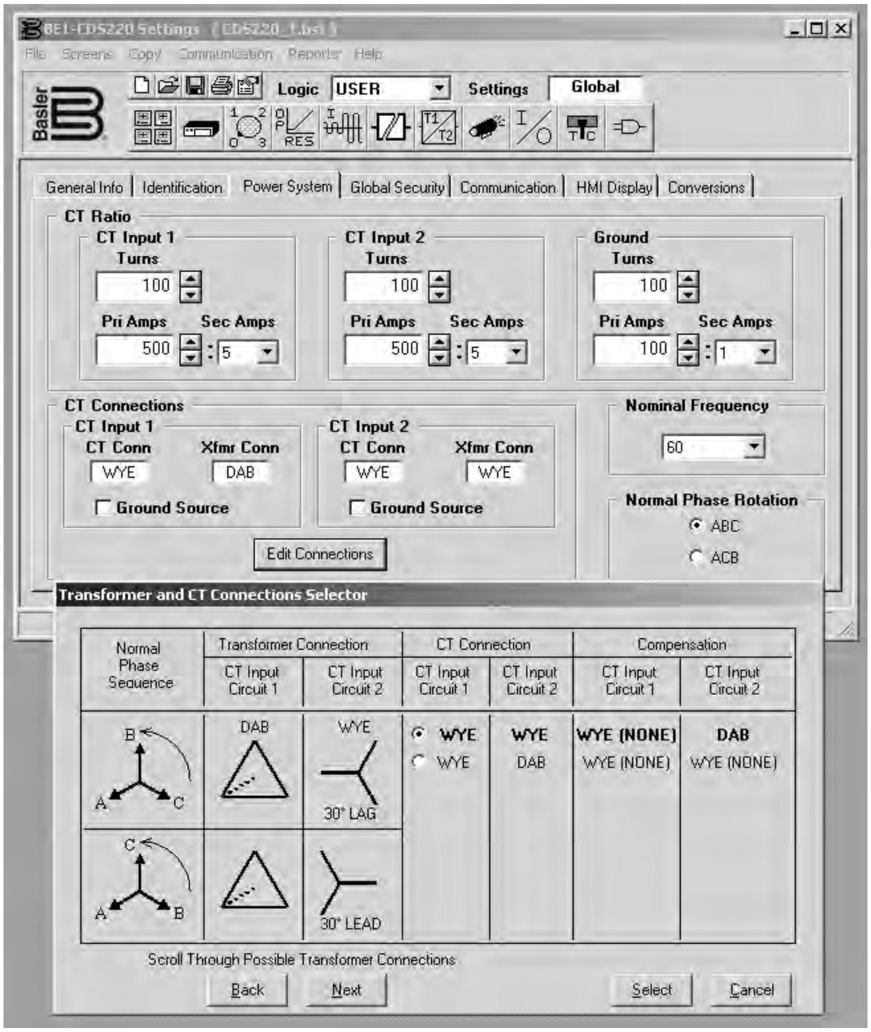


Figure 12 - BE1-CDS220 Setting Software

Testing at Final Settings

Delta compensation, especially if done internally by the relay, complicates testing. When done internally:

- It is difficult to calculate balanced current flow through the relay, especially when one has to simulate normal current flow with a three phase test set so one is unable to simulate a true 3 phase power flow condition, which requires six currents for complete modeling. However, faults are inherently unbalanced issues, so even if one has a 6 phase current source, it is a difficult task to calculate how a given fault translates to relay current, and further, to determine which test conditions the relay should or should not trip for.
- If testing is performed with only two currents, one phase at a time, the same difficulties arise. Due to inter-phase coupling in the delta compensation system, one needs to determine into which phases current needs to be injected, and the magnitude and phase relationships between these currents. On the relay input that monitors the transformer delta, one needs to inject current into two phases, 180^0 out of phase. For A phase current on the wye side, should one inject current on the delta side into A and B or A and C? Is the secondary in phase with the primary or 180^0 out of phase with the primary? Some may think there is supposed to be an additional +/- 30^0 phase shift (No, there is not).
- Determining balanced currents for a given tap setting can be complicated. Is there a sqrt(3) factor in the balanced current condition? Where? (It depends on the relay.)
- What is the minimum operate for one's application?
- What is the restraint quantity for one's application?
- What is the operate quantity for one's application?
- Is the minimum operate quantity the deciding factor in the trip decision, or is the operate/restraint quantity the deciding factor?
- To simplify testing, it would be easiest if one could reset the transformer differential relay to a Wye-Wye form, so that each of the phases would be independent, and then put the final settings back into the relay at the end. Many do not like this process for the obvious concerns of "Did I get the correct settings back into the relay? Do I know that the relay works at the settings I just entered?".

To address this issue, Basler has developed a Microsoft Excel™ spreadsheet that allows final settings to be entered into the spreadsheet and then tells how the relay will respond for a range of user supplied currents. The spreadsheet has 6 sheets:

a) 87T-Testing: For testing the relay with two single phase current sources.
b) 87T-Diff Calc-Isec: For determining relay response to an arbitrary injected current.
c) CDS Testing: For testing the CDS220 or 240 with two single phase current sources.
d) CDS220-Diff Calcs-Isec: For determining relay response to an arbitrary injected current.
e) CDS220-Diff Calcs-Ipri: For determining relay response to an arbitrary primary current. Includes CT connection and ratio effects.
f) CDS240-Diff Calcs-Isec: For determining relay response to an arbitrarily injected current.

To utilize the spreadsheet, one needs to be aware of appropriate connections of the test set to the relay. The test set current connections are provided in a basic fashion (described later) in the spreadsheets, but the spreadsheet must be used in conjunction with the connection diagrams given in the Instruction Manuals. Some appropriate figures from the BE1-87T and BE1-CDS220 Instruction Manuals (IM) are reproduced below. Figures 13 and 14, from the BE1-87T IM, show the basics of the connections required to test the BE1-87T. Test connections for the CDS relay are similar in concept, except the output (trip) contact is dependent on relay programming. Figures 15a-15d show the BE1-87T AC and DC terminals for the more common configurations, and Figures 16a and 16b show the AC and DC terminals for the BE1-CDS220. For the BE1-CDS240 connections, please refer to the IM.

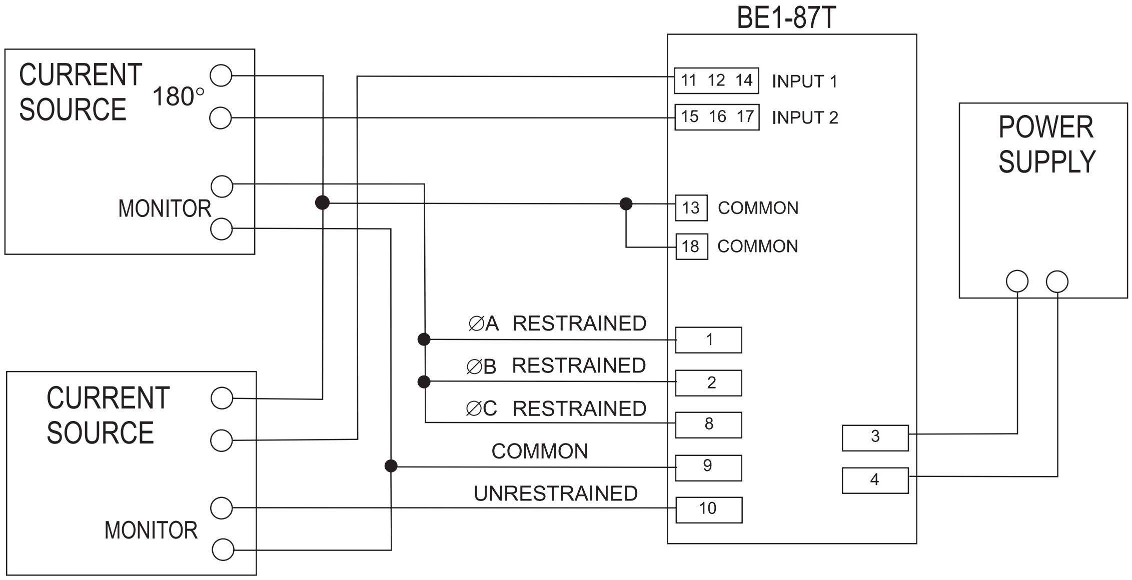


Figure 13 – BE1-87T, Three Phase, Single Input Type E, Output Option F

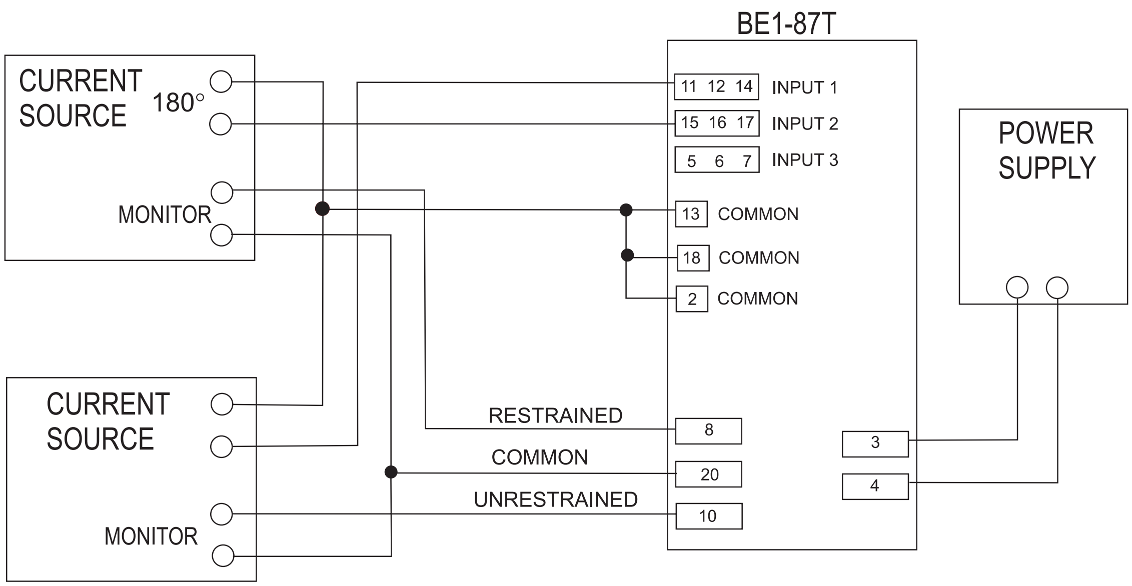


Figure 14 – BE1-87T, Three Phase, Sensing Input Type G, Output Option E

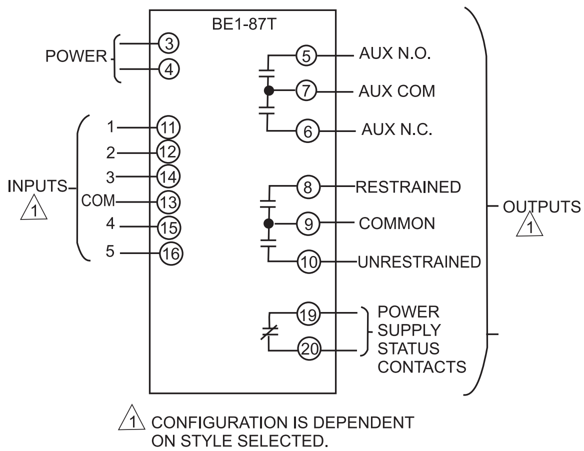


Figure 15a – BE1-87T, 1 phase

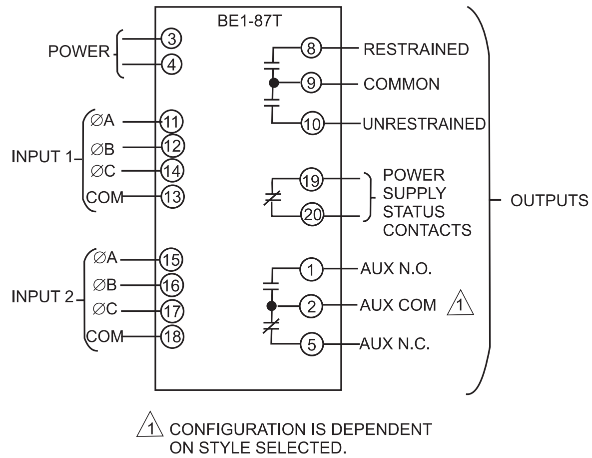


Figure 15b – BE1-87T, Three phase,
2 Input, Output Option F

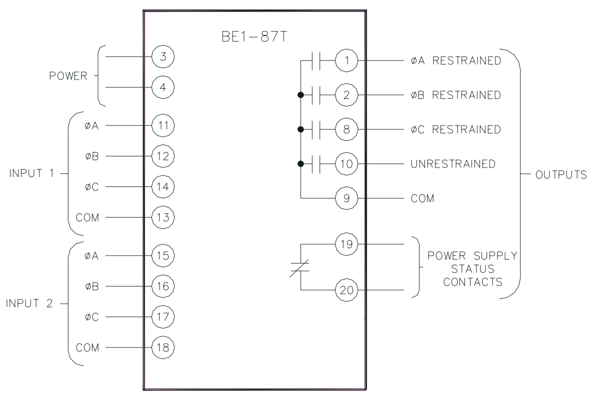


Figure 15c – BE1-87T, Three Phase,
2 Input, Output Option F

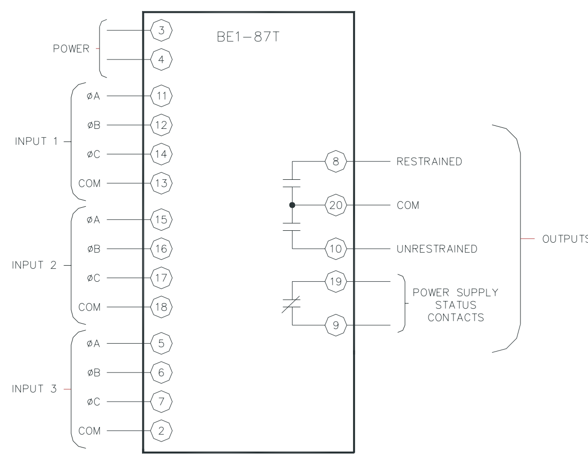


Figure 15d – BE1-87T, Three Phase,
3 Input, Output Option E

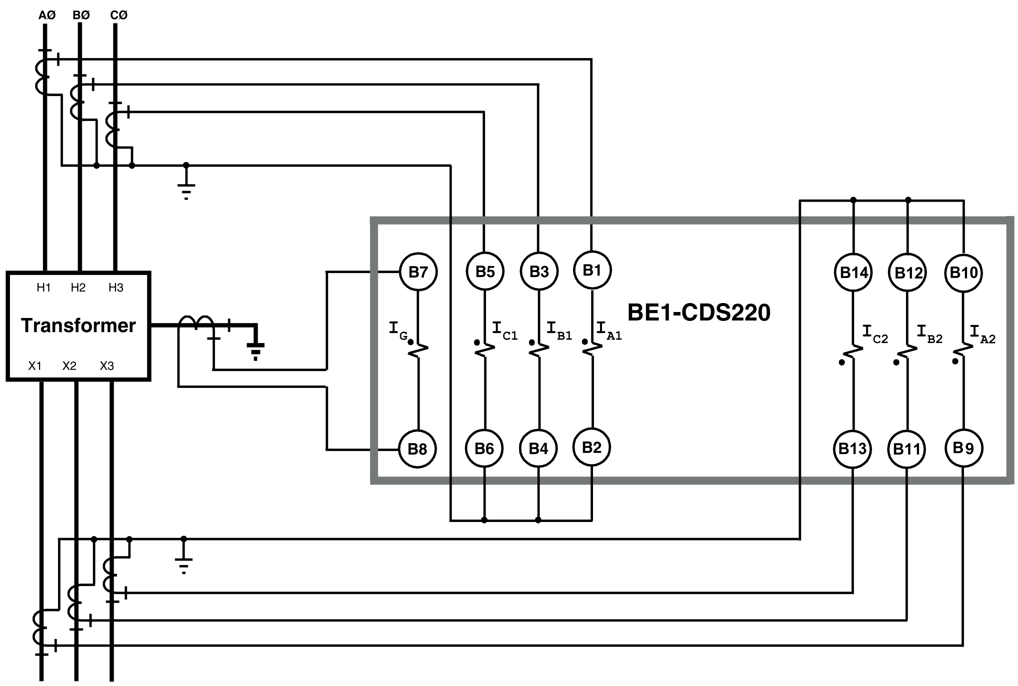


Figure 16a – BE1-CDS220, AC Connections

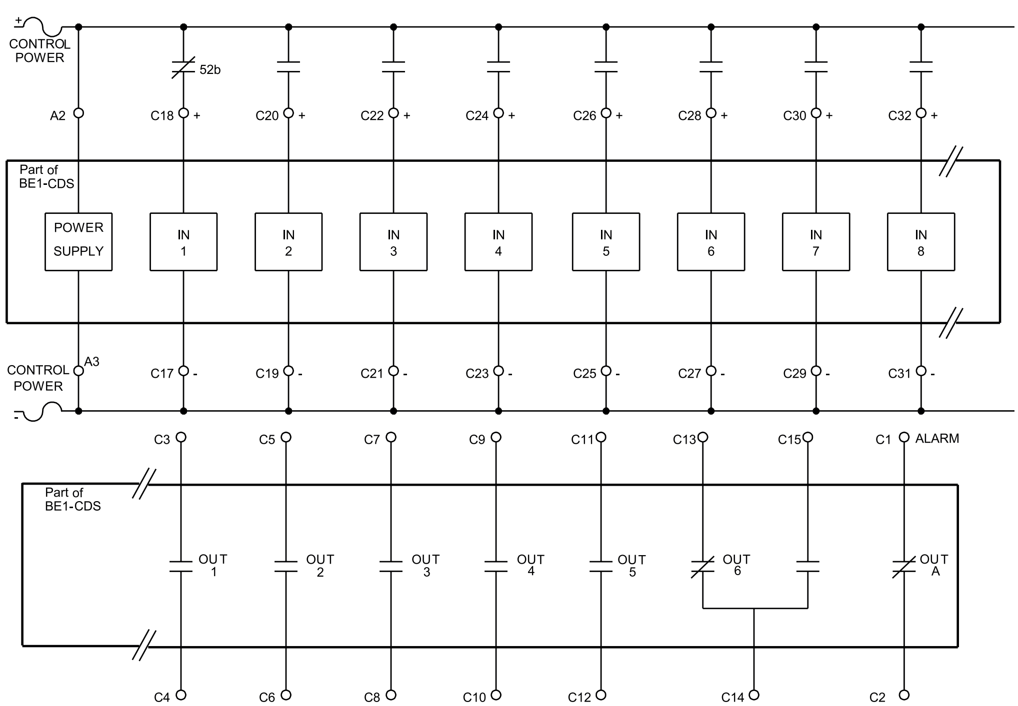
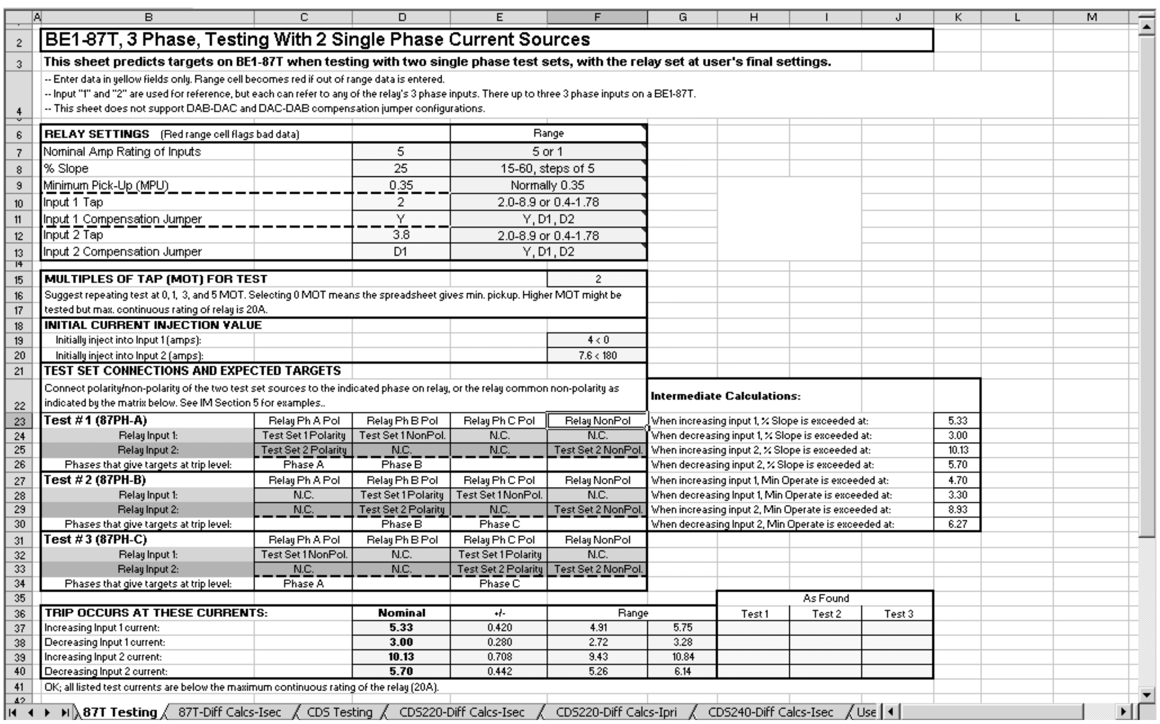


Figure 16b – BE1-CDS220, DC Connections

It might be best to learn how to utilize the sheets by simply opening them up and using them. To some extent, the purpose of each is determinable by the title. Of particular interest for testing are sheets a) and c). In each of these,

- The user inputs relay settings. With the CDS line, one needs to enter the net compensation used by the relay on each input. This is explained in chapter 3 of the IM's. Typically on numeric relays, the CTs are connected in wye, and if one has a D_{AB}-Wye transformer, the CT compensation is the reverse, so the compensation is Wye-D_{AB}.
- The user enters a current value in MOT that one wishes to use for the test. This is typically done at a few MOT, particularly 0, 1, 3, and maybe a higher number such as 5MOT, but testing at a high MOT results in high test currents that can be harder to work with and can damage inputs to the relays if left on too long.
- The user injects current on one phase on the relay input that monitors the transformer wye and on two phases on the relay input that monitors the transformer delta. The current on the delta side is "in and out" on the two phases under test, so that the current in the two inputs is 180^0 out of phase with one another.
- One begins with balanced current, and then raises and lowers two currents, one at a time, until an 87Phase trip occurs. The spreadsheet reports the current level where the trip should occur.
- For a CDS relay, one may need to include testing the 87ND function. Testing the 87ND is included in the spreadsheets.

A screen shot for each of the sheets is shown in figures 17a through 17f.



BE1-87T, 3 Phase, Testing With 2 Single Phase Current Sources

This sheet predicts targets on BE1-87T when testing with two single phase test sets, with the relay set at user's final settings.

-- Enter data in yellow fields only. Range cell becomes red if out of range data is entered.
-- Input "1" and "2" are used for reference, but each can refer to any of the relay's 3 phase inputs. There up to three 3 phase inputs on a BE1-87T.
-- This sheet does not support DAB-DAC and DAC-DAB compensation jumper configurations.

RELAY SETTINGS (Red range cell flags bad data)		Range
Nominal Amp Rating of Inputs	5	5 or 1
% Slope	25	15-60, steps of 5
Minimum Pick-Up (MPU)	0.35	Normally 0.35
Input 1 Tap	2	2.0-8.9 or 0.4-1.78
Input 1 Compensation Jumper	Y	Y, D1, D2
Input 2 Tap	3.8	2.0-8.9 or 0.4-1.78
Input 2 Compensation Jumper	D1	Y, D1, D2

MULTIPLES OF TAP (MOT) FOR TEST	2
Suggest repeating test at 0, 1, 3, and 5 MOT. Selecting 0 MOT means the spreadsheet gives min. pickup. Higher MOT might be tested but max. continuous rating of relay is 20A.	
INITIAL CURRENT INJECTION VALUE	
Initially inject into Input 1 (amps):	4 < 0
Initially inject into Input 2 (amps):	7.6 < 180

TEST SET CONNECTIONS AND EXPECTED TARGETS

Connect polarity/non-polarity of the two test set sources to the indicated phase on relay, or the relay common non-polarity as indicated by the matrix below. See IM Section 5 for examples..

Test # 1 (87PH-A)	Relay Ph A Pol	Relay Ph B Pol	Relay Ph C Pol	Relay NonPol
Relay Input 1:	Test Set 1 Polarity	Test Set 1 NonPol.	N.C.	N.C.
Relay Input 2:	Test Set 2 Polarity	N.C.	N.C.	Test Set 2 NonPol.
Phases that give targets at trip level:	Phase A	Phase B		
Test # 2 (87PH-B)	Relay Ph A Pol	Relay Ph B Pol	Relay Ph C Pol	Relay NonPol
Relay Input 1:	N.C.	Test Set 1 Polarity	Test Set 1 NonPol.	N.C.
Relay Input 2:	N.C.	Test Set 2 Polarity	N.C.	Test Set 2 NonPol.
Phases that give targets at trip level:		Phase B	Phase C	
Test # 3 (87PH-C)	Relay Ph A Pol	Relay Ph B Pol	Relay Ph C Pol	Relay NonPol
Relay Input 1:	Test Set 1 NonPol.	N.C.	Test Set 1 Polarity	N.C.
Relay Input 2:	N.C.	N.C.	Test Set 2 Polarity	Test Set 2 NonPol.
Phases that give targets at trip level:	Phase A		Phase C	

Intermediate Calculations:	
When increasing input 1, % Slope is exceeded at:	5.33
When decreasing input 1, % Slope is exceeded at:	3.00
When increasing input 2, % Slope is exceeded at:	10.13
When decreasing input 2, % Slope is exceeded at:	5.70
When increasing input 1, Min Operate is exceeded at:	4.70
When decreasing Input 1, Min Operate is exceeded at:	3.30
When increasing input 2, Min Operate is exceeded at:	8.93
When decreasing Input 2, Min Operate is exceeded at:	6.27

TRIP OCCURS AT THESE CURRENTS:	Nominal	+/-	Range		As Found Test 1	As Found Test 2	As Found Test 3
Increasing Input 1 current:	**5.33**	0.420	4.91	5.75			
Decreasing Input 1 current:	**3.00**	0.280	2.72	3.28			
Increasing Input 2 current:	**10.13**	0.708	9.43	10.84			
Decreasing Input 2 current:	**5.70**	0.442	5.26	6.14			

OK; all listed test currents are below the maximum continuous rating of the relay (20A).

Figure 17a - BE1-87T, Testing with 2 Single Phase Current Sources

Note how to read the connection instructions in sheet Fig 17a, which describes the test configuration for the BE1-87T. Examine test #1 connections, seen on lines 24-25. In these cells, the connections for this transformer, for testing the Phase A element, are: a) connect test source #1 to inject current into phase A and out of phase B, then b) connect test source #2 to inject current into phase A and out of the input common connection. A very similar process will be seen for figure 17c, which is the similar sheet for the CDS2x0. However, make note of cell B33, which says, “Jumper non-polarities on each input together.” The jumpers are installed to effectively create the same current common connection that is found in the BE1-87T relay. When the spreadsheet refers to connecting the test set to “Relay Non-Polarity”, it means connecting to this common connection of the non-polarity inputs.

BE1-87T, 3 Phase, Differential Calculations, Arbitrary Isec.

This sheet predicts tripping of a BE1-87T for a set of two user-defined CT secondary current inputs

-- Enter data in yellow fields only. Blue cells are calculated by the spreadsheet.
-- Input 1 and 2 are used for reference; each can refer to any of the relay's 3-phase inputs. There up to three 3-phase inputs on a BE1-87T.
-- The spreadsheet reproduces the differential calculations of the BE1-87T to assist in determining if a trip should occur for a given test current.
-- Range cells will be green normally, but turn red to flag out-of-range settings.
-- Recall the relay expects current reversal across the xfmr, so balanced currents are shifted by 150, 180, or -150 degrees in most applications. For instance, for balanced 3 phase current, current at Input 2 should be shifted by 180deg if jumpers are Y-Y, +150deg if jumpers are Y-D1, and -150deg if jumpers are Y-D2.

RELAY SETTINGS (Red range cell flags bad data)		Range
Nominal Amp Rating of Inputs	5	5 or 1
% Slope	30	15-60, steps of 5
Minimum Pickup (MPU), per unit	0.35	See Cell Comment
Input 1 Tap	5	2.0-8.9 or 0.4-1.78
Input 1 Compensation Jumper	Y	Y, D1, D2
Input 2 Tap	5.2	2.0-8.9 or 0.4-1.78
Input 2 Compensation Jumper	D2	Y, D1, D2

INJECTED CURRENT AT INPUT 1		
(Single phase entry sufficient)	Mag.	Angle
Current @ Input 1, Ph A	10	0
Current @ Input 1, Ph B	10	-120
Current @ Input 1, Ph C	10	120
INJECTED CURRENTS AT INPUT 2		
	Mag.	Angle
Current @ Input 2, Ph A	6	150
Current @ Input 2, Ph B	6	30
Current @ Input 2, Ph C	6	-90

Current Inputs, Per Unit of Tap:	Mag.	Angle
Input 1, Ph A	2.000	0
Input 1, Ph B	2.000	-120
Input 1, Ph C	2.000	120
Input 2, Ph A	1.154	150
Input 2, Ph B	1.154	30
Input 2, Ph C	1.154	-90
Restraint, with Compensation Jumper Effects		
Input 1, A Comparator	2.000	0
Input 1, B Comparator	2.000	-120
Input 1, C Comparator	2.000	120
Input 2, A Comparator	1.999	180
Input 2, B Comparator	1.999	60
Input 2, C Comparator	1.999	-60
Effective Restraint (Largest Restraint x Slope)		
A Comparator	0.600	
B Comparator	0.600	
C Comparator	0.600	
Mag. Operate Current (Restraint 1 - Restraint 2)		
A Comparator	0.001	
B Comparator	0.001	
C Comparator	0.001	
Trip? (Op>MPU? & Op>Restraint?)		
A Comparator	**No**	
B Comparator	**No**	
C Comparator	**No**	

Intermediate Calculations							
D1, D2 Jumper Compensation Equations:							
Input 1, Rectangular format			D1, D2 Equations				
	Real	Imag		Real	Imag	Mag	Angle
A	2.0000	0.0000	D1;1A-1C	3.0000	-1.7321	3.4641	-30.0
B	-1.0000	-1.7321	D1;1B-1A	-3.0000	-1.7321	3.4641	-150.0
C	-1.0000	1.7321	D1;1C-1B	0.0000	3.4641	3.4641	90.0
			D2;1A-1B	3.0000	1.7321	3.4641	30.0
			D2;1B-1C	0.0000	-3.4641	3.4641	-90.0
			D2;1C-1A	-3.0000	1.7321	3.4641	150.0
Input 2, Rectangular format			D1, D2 Equations				
A	-0.9993	0.5769	D1;2A-2C	-0.9993	1.7308	1.9985	120.0
B	0.9993	0.5769	D1;2B-2A	1.9985	0.0000	1.9985	0.0
C	0.0000	-1.1538	D1;2C-2B	-0.9993	-1.7308	1.9985	-120.0
			D2;2A-2B	-1.9985	0.0000	1.9985	180.0
			D2;2B-2C	0.9993	1.7308	1.9985	60.0
			D2;2C-2A	0.9993	-1.7308	1.9985	-60.0

Convert Restraint to Rectangular format					
		X	jY		
Input 1	A	2.0000	0.0000		
	B	-1.0000	-1.7321		
	C	-1.0000	1.7321		
Input 2	A	-1.9985	0.0000		
	B	0.9993	1.7308		
	C	0.9993	-1.7308		
Sum Restraint to find Operate Current					
		X	jY	Mag	Angle
Sum	1A+2A	0.0015	0.0000	0.0015	----
	1B+2B	-0.0007	-0.0013	0.0015	----
	1C+2C	-0.0007	0.0013	0.0015	----

87T Testing / **87T-Diff Calcs-Isec** / CDS Testing / CDS220-Diff Calcs-Isec / CDS220-Diff Calcs-Ipri / CDS240-Diff Calcs-Isec / Use

Figure 17b - BE1-87T Differential Calculations - Arbitrary Isec

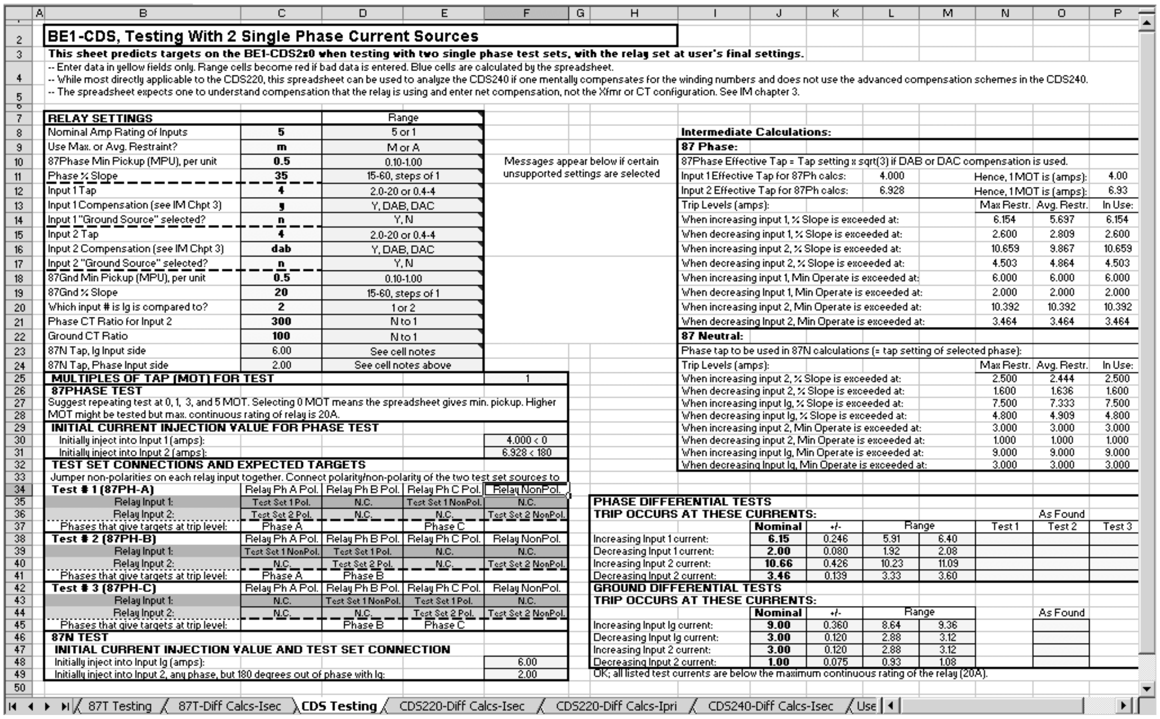


Figure 17c - BE1-CDS, Testing with Two Single Phase Current Sources

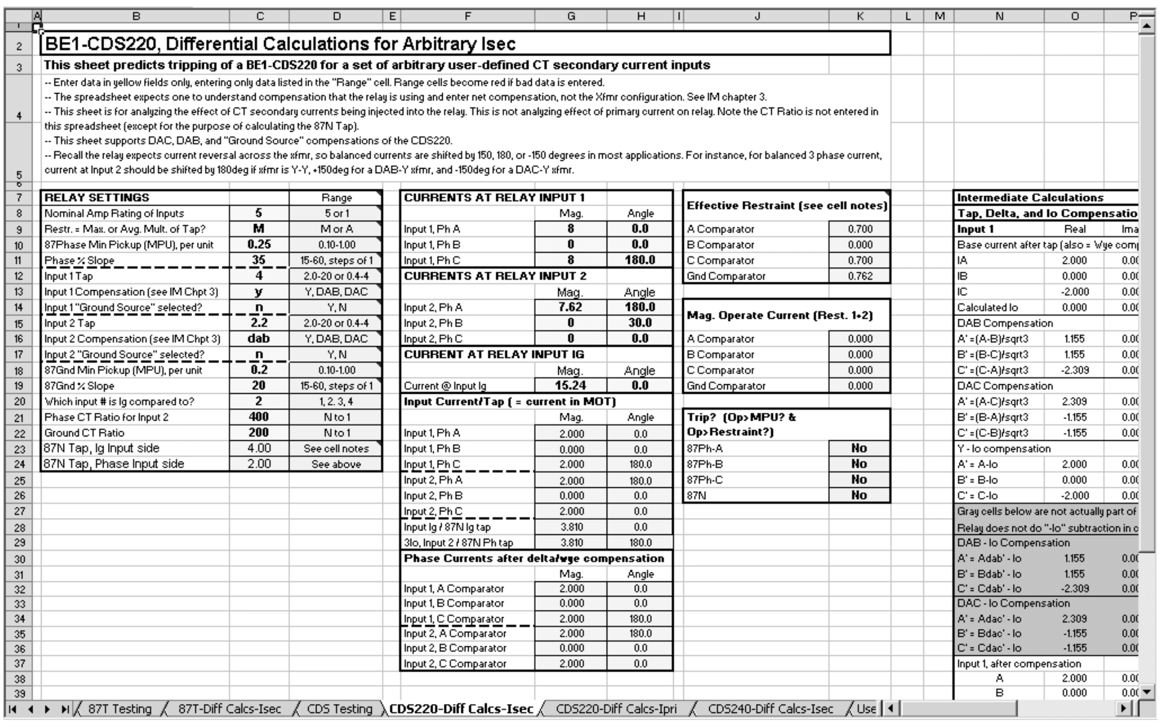
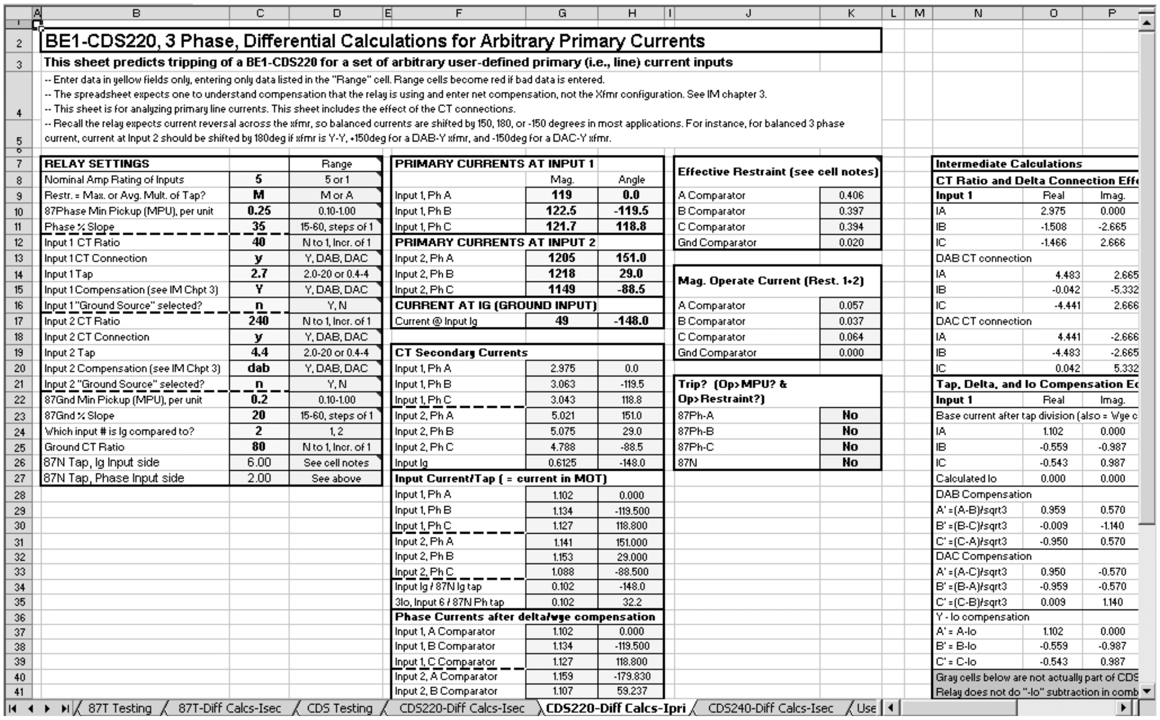


Figure 17d - BE1-CDS220 - Differential Calculations for Arbitrary Isec



BE1-CDS220, 3 Phase, Differential Calculations for Arbitrary Primary Currents

This sheet predicts tripping of a BE1-CDS220 for a set of arbitrary user-defined primary (i.e., line) current inputs

-- Enter data in yellow fields only, entering only data listed in the "Range" cell. Range cells become red if bad data is entered.
-- The spreadsheet expects one to understand compensation that the relay is using and enter net compensation, not the Xfmr configuration. See IM chapter 3.
-- This sheet is for analyzing primary line currents. This sheet includes the effect of the CT connections.
-- Recall the relay expects current reversal across the xfmr, so balanced currents are shifted by 150, 180, or -150 degrees in most applications. For instance, for balanced 3 phase current, current at Input 2 should be shifted by 180deg if xfmr is Y-Y, +150deg for a DAB-Y xfmr, and -150deg for a DAC-Y xfmr.

RELAY SETTINGS		Range
Nominal Amp Rating of Inputs	5	5 or 1
Restr. = Max. or Avg. Mult. of Tap?	M	M or A
87Phase Min Pickup (MPU), per unit	0.25	0.10-1.00
Phase % Slope	35	15-60, steps of 1
Input 1 CT Ratio	40	N to 1, Incr. of 1
Input 1 CT Connection	y	Y, DAB, DAC
Input 1 Tap	2.7	2.0-20 or 0.4-4
Input 1 Compensation (see IM Chpt 3)	Y	Y, DAB, DAC
Input 1 "Ground Source" selected?	n	Y, N
Input 2 CT Ratio	240	N to 1, Incr. of 1
Input 2 CT Connection	y	Y, DAB, DAC
Input 2 Tap	4.4	2.0-20 or 0.4-4
Input 2 Compensation (see IM Chpt 3)	dab	Y, DAB, DAC
Input 2 "Ground Source" selected?	n	Y, N
87Gnd Min Pickup (MPU), per unit	0.2	0.10-1.00
87Gnd % Slope	20	15-60, steps of 1
Which input # is Ig compared to?	2	1, 2
Ground CT Ratio	80	N to 1, Incr. of 1
87N Tap, Ig Input side	6.00	See cell notes
87N Tap, Phase Input side	2.00	See above

PRIMARY CURRENTS AT INPUT 1	Mag.	Angle
Input 1, Ph A	119	0.0
Input 1, Ph B	122.5	-119.5
Input 1, Ph C	121.7	118.8
PRIMARY CURRENTS AT INPUT 2		
Input 2, Ph A	1205	151.0
Input 2, Ph B	1218	29.0
Input 2, Ph C	1149	-88.5
CURRENT AT IG (GROUND INPUT)		
Current @ Input Ig	49	-148.0

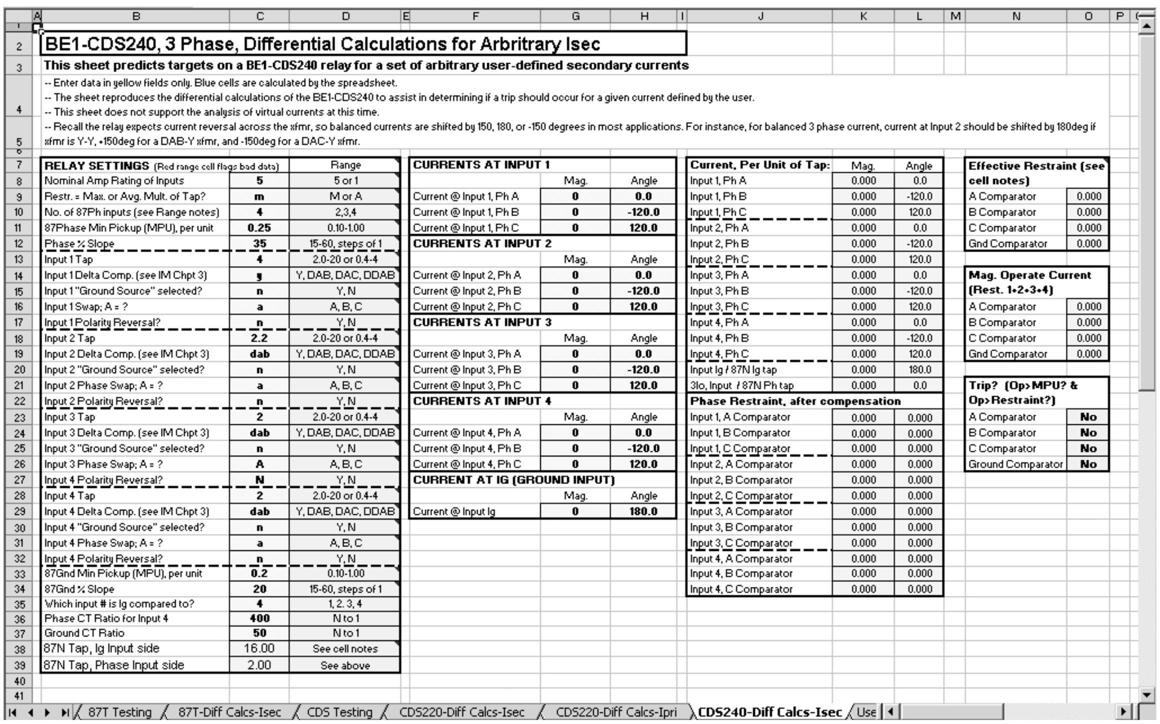
CT Secondary Currents		
Input 1, Ph A	2.975	0.0
Input 1, Ph B	3.063	-119.5
Input 1, Ph C	3.043	118.8
Input 2, Ph A	5.021	151.0
Input 2, Ph B	5.075	29.0
Input 2, Ph C	4.788	-88.5
Input Ig	0.6125	-148.0
Input Current/Tap (= current in MOT)		
Input 1, Ph A	1.102	0.000
Input 1, Ph B	1.134	-119.500
Input 1, Ph C	1.127	118.800
Input 2, Ph A	1.141	151.000
Input 2, Ph B	1.153	29.000
Input 2, Ph C	1.088	-88.500
Input Ig / 87N Ig tap	0.102	-148.0
3Io, Input 6 / 87N Ph tap	0.102	32.2
Phase Currents after delta/wye compensation		
Input 1, A Comparator	1.102	0.000
Input 1, B Comparator	1.134	-119.500
Input 1, C Comparator	1.127	118.800
Input 2, A Comparator	1.159	-179.830
Input 2, B Comparator	1.107	59.237

Effective Restraint (see cell notes)	
A Comparator	0.406
B Comparator	0.397
C Comparator	0.394
Gnd Comparator	0.020
Mag. Operate Current (Rest. 1+2)	
A Comparator	0.057
B Comparator	0.037
C Comparator	0.064
Gnd Comparator	0.000
Trip? (Op>MPU? & Op>Restraint?)	
87Ph-A	No
87Ph-B	No
87Ph-C	No
87N	No

Intermediate Calculations		
CT Ratio and Delta Connection Eff		
Input 1	Real	Imag.
IA	2.975	0.000
IB	-1.508	-2.665
IC	-1.466	2.666
DAB CT connection		
IA	4.483	2.665
IB	-0.042	-5.332
IC	-4.441	2.666
DAC CT connection		
IA	4.441	-2.666
IB	-4.483	-2.665
IC	0.042	5.332
Tap, Delta, and Io Compensation Ec		
Input 1	Real	Imag.
Base current after tap division (also = Wye c		
IA	1.102	0.000
IB	-0.559	-0.987
IC	-0.543	0.987
Calculated Io	0.000	0.000
DAB Compensation		
A' =(A-B)/sqrt3	0.959	0.570
B' =(B-C)/sqrt3	-0.009	-1.140
C' =(C-A)/sqrt3	-0.950	0.570
DAC Compensation		
A' =(A-C)/sqrt3	0.950	-0.570
B' =(B-A)/sqrt3	-0.959	-0.570
C' =(C-B)/sqrt3	0.009	1.140
Y - Io compensation		
A' = A-Io	1.102	0.000
B' = B-Io	-0.559	-0.987
C' = C-Io	-0.543	0.987
Gray cells below are not actually part of CDS		
Relay does not do "-Io" subtraction in comb		

87T Testing / 87T-Diff Calcs-Isec / CDS Testing / CDS220-Diff Calcs-Isec / CDS220-Diff Calcs-Ipri / CDS240-Diff Calcs-Isec / Use

Figure 17e - BE1-CDS220 - Differential Calculations for Arbitrary Primary Currents



BE1-CDS240, 3 Phase, Differential Calculations for Arbritrary Isec

This sheet predicts targets on a BE1-CDS240 relay for a set of arbitrary user-defined secondary currents

-- Enter data in yellow fields only. Blue cells are calculated by the spreadsheet.
-- The sheet reproduces the differential calculations of the BE1-CDS240 to assist in determining if a trip should occur for a given current defined by the user.
-- This sheet does not support the analysis of virtual currents at this time.
-- Recall the relay expects current reversal across the xfmr, so balanced currents are shifted by 150, 180, or -150 degrees in most applications. For instance, for balanced 3 phase current, current at Input 2 should be shifted by 180deg if xfmr is Y-Y, +150deg for a DAB-Y xfmr, and -150deg for a DAC-Y xfmr.

RELAY SETTINGS (Red range cell flags bad data)		Range
Nominal Amp Rating of Inputs	5	5 or 1
Restr. = Max. or Avg. Mult. of Tap?	m	M or A
No. of 87Ph inputs (see Range notes)	4	2,3,4
87Phase Min Pickup (MPU), per unit	0.25	0.10-1.00
Phase % Slope	35	15-60, steps of 1
Input 1 Tap	4	2.0-20 or 0.4-4
Input 1 Delta Comp. (see IM Chpt 3)	y	Y, DAB, DAC, DDAB
Input 1 "Ground Source" selected?	n	
Input 1 Swap; A = ?	a	A, B, C
Input 1 Polarity Reversal?	n	Y, N
Input 2 Tap	2.2	2.0-20 or 0.4-4
Input 2 Delta Comp. (see IM Chpt 3)	dab	Y, DAB, DAC, DDAB
Input 2 "Ground Source" selected?	n	Y, N
Input 2 Phase Swap; A = ?	a	A, B, C
Input 2 Polarity Reversal?	n	Y, N
Input 3 Tap	2	2.0-20 or 0.4-4
Input 3 Delta Comp. (see IM Chpt 3)	dab	Y, DAB, DAC, DDAB
Input 3 "Ground Source" selected?	n	Y, N
Input 3 Phase Swap; A = ?	A	A, B, C
Input 4 Polarity Reversal?	N	Y, N
Input 4 Tap	2	2.0-20 or 0.4-4
Input 4 Delta Comp. (see IM Chpt 3)	dab	Y, DAB, DAC, DDAB
Input 4 "Ground Source" selected?	n	Y, N
Input 4 Phase Swap; A = ?	a	A, B, C
Input 4 Polarity Reversal?	n	Y, N
87Gnd Min Pickup (MPU), per unit	0.2	0.10-1.00
87Gnd % Slope	20	15-60, steps of 1
Which input # is Ig compared to?	4	1, 2. 3, 4
Phase CT Ratio for Input 4	400	N to 1
Ground CT Ratio	50	N to 1
87N Tap, Ig Input side	16.00	See cell notes
87N Tap, Phase Input side	2.00	See above

CURRENTS AT INPUT 1	Mag.	Angle
Current @ Input 1, Ph A	0	0.0
Current @ Input 1, Ph B	0	-120.0
Current @ Input 1, Ph C	0	120.0
CURRENTS AT INPUT 2	Mag.	Angle
Current @ Input 2, Ph A	0	0.0
Current @ Input 2, Ph B	0	-120.0
Current @ Input 2, Ph C	0	120.0
CURRENTS AT INPUT 3	Mag.	Angle
Current @ Input 3, Ph A	0	0.0
Current @ Input 3, Ph B	0	-120.0
Current @ Input 3, Ph C	0	120.0
CURRENTS AT INPUT 4	Mag.	Angle
Current @ Input 4, Ph A	0	0.0
Current @ Input 4, Ph B	0	-120.0
Current @ Input 4, Ph C	0	120.0
CURRENT AT IG (GROUND INPUT)	Mag.	Angle
Current @ Input Ig	0	180.0

Current, Per Unit of Tap:	Mag.	Angle
Input 1, Ph A	0.000	0.0
Input 1, Ph B	0.000	-120.0
Input 1, Ph C	0.000	120.0
Input 2, Ph A	0.000	0.0
Input 2, Ph B	0.000	-120.0
Input 2, Ph C	0.000	120.0
Input 3, Ph A	0.000	0.0
Input 3, Ph B	0.000	-120.0
Input 3, Ph C	0.000	120.0
Input 4, Ph A	0.000	0.0
Input 4, Ph B	0.000	-120.0
Input 4, Ph C	0.000	120.0
Input Ig / 87N Ig tap	0.000	180.0
3Io, Input / 87N Ph tap	0.000	0.0
Phase Restraint, after compensation		
Input 1, A Comparator	0.000	0.000
Input 1, B Comparator	0.000	0.000
Input 1, C Comparator	0.000	0.000
Input 2, A Comparator	0.000	0.000
Input 2, B Comparator	0.000	0.000
Input 2, C Comparator	0.000	0.000
Input 3, A Comparator	0.000	0.000
Input 3, B Comparator	0.000	0.000
Input 3, C Comparator	0.000	0.000
Input 4, A Comparator	0.000	0.000
Input 4, B Comparator	0.000	0.000
Input 4, C Comparator	0.000	0.000

Effective Restraint (see cell notes)	
A Comparator	0.000
B Comparator	0.000
C Comparator	0.000
Gnd Comparator	0.000
Mag. Operate Current (Rest. 1+2+3+4)	
A Comparator	0.000
B Comparator	0.000
C Comparator	0.000
Gnd Comparator	0.000
Trip? (Op>MPU? & Op>Restraint?)	
A Comparator	No
B Comparator	No
C Comparator	No
Ground Comparator	No

87T Testing / 87T-Diff Calcs-Isec / CDS Testing / CDS220-Diff Calcs-Isec / CDS220-Diff Calcs-Ipri / CDS240-Diff Calcs-Isec / Use

Figure 17f - BE1-CDS240 - Differential Calculations for Arbitrary Isec

Conclusion

This paper basically is a short review of the concept of transformer differential relaying and the theory of operation of Basler differential relays. Likely, the most important thing to be learned from this is that there are tools available to assist one in testing relays, especially when testing at the user's final settings. See the references below for these tools. Note that they are available for free download at the Basler Electric web site.

References

All references below are available at www.basler.com. All are free/no charge, except that some contact info needs to be provided upon requesting to download the material. To obtain BESTCOMS, a download password needs to be requested, which takes a few hours to process.

1) "*Three Phase Transformer Winding Configurations and Differential Relay Compensation,*" Larry Lawhead, Randy Hamilton, John Horak, (Paper presented at Western Protective Relay Conference October 2004).
2) Basler BE1-87T Instruction Manual, Publication 9 1713 00 990.
3) Basler BE1-CDS220 Instruction Manual, Publication 9 3139 00 990.
4) Basler BE1-CDS240 Instruction Manual, Publication 9 3652 00 990.
5) "*BE1-87T, 3 Phase Versions: Understanding Targets and Testing the Internal Phase Shifting Network*," Basler Electric Application Note PC87T02.
6) Microsoft Excel™ Spreadsheet "*87TWOFLT.XLS.*" This is a spreadsheet for assisting in the setting of a BE1-87T relay. There is also a spreadsheet "87TWFLT.XLS" that has some additional basic calculations, but there are some additional confusion factors involved in using this spreadsheet.
7) Microsoft Excel™ Spreadsheet "*CDS_SETTINGS_R#.XLS.* This is a spreadsheet for assisting in the setting of a BE1-CDS220/240 relay.
8) BESTCOMS for the BE1-CDS220. Setting software for the BE1-CDS220.
9) BESTCOMS for the BE1-CDS240. Setting software for the BE1-CDS240.
10) Microsoft Excel™ Spreadsheet "XfmrDiffAnalysis_R1.XLS. This spreadsheet analyzes the response of the BE1-87T and BE1-CDS relays to various currents, and assists in testing relays at final settings.

Basler Electric®
www.basler.com

Highland, Illinois USA
Tel: +1 618.654.2341
Fax: +1 618.654.2351
email: info@basler.com

Suzhou, P.R. China
Tel: +86 512.8227.2888
Fax: +86 512.8227.2887
email: chinainfo@basler.com