f. Connect terminals 7 and 8 together and apply rated ac voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts. If contact arm does not float in the gap then rotate the core 90 degrees and readjust.

g. Use test connection #5 Set $V_{1F\text{-}2F}$ = 2 volts = V_{fault}. Note that to set this voltage you have to set voltages $V_{A\text{-}1F} = V_{B\text{-}2F}$ first where:

$$V_{A-1F} = V_{B-2F} = \frac{V_{in} - V_{fault}}{2}$$

if V_{in} = 120 volts

V_{fault} = 2 volts

$V_{A-1F} = V_{B-2F} = \frac{120 - 2}{2} = 59$ volts. Now trim up either voltage to get V_{fault} = 2 volts.

The current required to close contacts of the top unit should be:

Relay Range	.2 - 4.5	.75 - 21.2	1.3 - 36.6
Trip Current amperes	0.9 - 1.10	0.202 - 0.227	.115 - .135
Phase-shifter Set at current lagging	75°	75°	75°

With no current, relay contacts should stay open. If relay contacts are closed recheck voltage settings, incorrect voltage setting may result in negative sequence voltage phasing.

Set phase-shifter for maximum torque angle. Check pickup current. It should be within the limits specified above if not rotate core slightly until pickup current falls within specified range. Connect relay for 2-3 (Test No. 6) and recheck pickup. It should be within limits specified. For best trip calibration results adjust core so that trip current for Test No. 5 and No. 6 are equal.

Connect relay for Test No. 7. Check trip current. Use XL_{AC} adjustable reactor to bring relay response within the specified limits. Moving red lead from front terminal to rear terminal or from rear terminal to front terminal of the reactor will reverse contact action of the unit. Screwing in or out the adjustable core should bring unit response within the limits. There are three possible connections for reactor coils; series (loose coil termination leads connected together), parallel (each loose lead connected to the fixed terminals of the other coil), single front coil (omit loose lead of the rear coil from the circuit, bury it in insulation tubing). The reactor connections, should not require any changes unless some of the components of the phase-to-phase unit circuitry have been exchanged. Tighten up the locking nut when finished. If the unit does not operate within the specified limits, then rotate the cylinder unit core 90 degrees and repeat test numbers 5, 6, and 7.

15.1 MAXIMUM TORQUE ANGLE CHECK

a. Use the No. 2 test switch position and lead connections. This connection is for checking the maximum torque angle of the TAB compensator.

Set voltages and currents as per chart below.

Relay Range	0.2 - 4.5	.75 - 21.2	1.27 - 36.6
$V_{1F\text{-}2F} = V2Fv3F$ I_{test} (amp)	10 12	50 10.0	50 6.0

Rotate the phase-shifter to find two angles $_1$ and $_2$, at which the top unit contacts just close. The maximum torque angle for the phase-to-phase unit then is $\frac{_1 + _2}{2} - 30$ degrees. Do not allow more than 2 degrees error in this adjustment. Tighten the locking nut.

I_{test}, for other than nominal maximum torque angle, current should be:

$$I = \frac{I_T \sin \ _m}{\sin} \qquad \text{[Equ. 23]}$$

Where $_m$ = original maximum torque
= recalibrated maximum torque angle

Example 7

For $_m$ = I_{test} = 10 amps

For new = 60°

New $I_{test} = \frac{10 \quad \sin 75}{\sin 60} = 11.1$ amps

Increasing P_{2A} or P_{2C} value, rotation in clockwise direction maximum torque angle, and conversely, decreasing the P_{2A} or P_{2C} value results in smaller angles.

For lower maximum torque angle than 70 degrees move red lead on fixed phase-shifting resistor R_{2A} and R_{2C} to the opposite terminal. Where R_{2A} and R_{2C} are adjustable, use it in combination with P_{2A} and P_{2C} without moving the lead.

b. Use the No. 4 test connection and repeat the procedure above for checking the T_{BC} compensator.

15.2 SPRING RESTRAINT

a. Use test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush No. 1 is connected to 3F and Brush No. 2 is connected to 1F.

b. Adjust the voltage V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving-contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush No. 1 to 1F and Brush No. 2 to 3F. ***De-energize the relay.*** Spring should reset the contacts.

15.3 CONTACT ADJUSTMENT

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

15.4 IMPEDANCE CHECK

Using the connections for Test Nos. 5, 6, and 7, set the phase-shifter so that the current lags voltage by $_m$. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is

$Z_R = \frac{V_{L-L}}{2I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

The current required to close contacts of the top unit should be:

Relay Range	.2 - 4.5	.75 - 21.2	1.3 - 36.6
$V_{fault} = V_{1F-2F}$ (Volts)	30	30	30
Trip Current (amps)	13.3 - 14.7	2.85 - 3.15	1.63 - 1.80
Phase-shifter Set at current lagging V_{1F-2F} ($_m$)	75°	75°	75°

For current limits when $_m$ maximum torque angle is not 75°, multiply the values above by $\frac{\sin 75}{\sin}$ where = new maximum torque angle for which the relay was calibrated.

For test voltages to be of correct sequence and values, use the following equation:

$$V_{1-1F} = V_{2-2F} = \frac{V_{in} - V_{fault}}{2} \quad \text{[Equ. 24]}$$

15.5 INDICATING CONTACTOR SWITCH (ICS)

Close the main relay contacts and pass-sufficient dc current through the trip circuit to close the contacts of the ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2–2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

16.0 COMPENSATOR CHECK

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

a. Set T, T_A, T_B, T_B, and T_C

on the 1.23	tap for	.2	-	4.5	range
5.80	tap for	.75	-	21.2	range
10.0	tap for	1.3	-	36.6	range

b. Disconnect the "L" leads of sections M, M_A, and M_C and the red-marked leads of R_3, R_{2A}, and R_{2C} (with resistor loading removed = 90°.

c. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 10 amperes ac current in terminal 19 and out of terminal 13.

d. Measure the compensator voltage V_C with a high resistance voltmeter (5,000 ohm/volt) as tabulated below. Refer to Figure 1 (page 35) for the location of R_3, R_{2A} AND R_{2C}.

Measure V_C Between		Voltmeter Reading
Lead	and Fixed End of	
"L" of M	R3	$V_C = 1.5\ IT \dfrac{\sin}{\sin 75}$
"L" of M_A	R2A	$V_C = 2\ IT \dfrac{\sin}{\sin 75}$
"L" of M_C	R2C	

Use sin 60° for .2 - 4.5 range

Example 8

For .75 - 21 ohm range T = 5.8 relay 3-phase compensator will read V_C = 90.1 volts and for phase-to-phase compensators where T-5.8 the voltages are:

V_C = 120 volts (phase A)
V_C = 120 volts (phase C)

Accuracy of the measurement will depend on the instrumentation used. Factory adjusted compensator is within 0.5% on maximum tap and 1% on all other taps. A realistic tolerance should be allowed for accuracy of the primary current measurement, and the accuracy of the voltmeter to be used to arrive at what is a "good" compensator. A zero voltage reading may be caused by open potentiometer or compensator.

Additional measurements on the compensator can be made to check the compensator tap sequence, and to check on the condition of all (except terminals 8-9-circuit of the 3-phase unit) relay circuits.

With relay energized with 120 Vac only, and all S-settings set = 1, and M = +15, check voltage drops starting at the minimum tap and each successive "T" tap. Voltage readings will start at the millivolt level, and increase with successive tap values. Erratic voltage reading will indicate open tap. These type of readings could be taken at any relay setting except when comparing any two relays, or readings from the same relay at different times it should be clear that relay settings for which measurements are taken should be identical. The table below gives typical readings for settings specified above. Use this table as a guide only.

0.2 - 4.5 Ohms Range	
T_A, T_B, T_B, T_C	T
.003 - .006	.008 - .016
.008 - .011	.018 - .031
.017 - .021	.004 - .063
.026 - .031	.006 - .088
.040 - .047	.100 - .138
.060 - .068	.145 - .210
.75 - 21.2 Ohms Range	
T_A, T_B, T_B, T_C	T
.015 - .026	.033 - .050
.032 - .054	.072 - .092
.072 - .110	.145 - .190
.125 - .190	.260 - .190
.200 - .290	.400 - .340
.295 - .470	.645 - .800
1.3 - 36.6 Ohms Range	
T_A, T_B, T_B, T_C	T
.038 - .052	.055 - .070
.080 - .100	.105 - .150
.150 - .200	.220 - .300
.290 - .340	.390 - .540
.450 - .535	.600 - .850
.700 - .860	.950 - 1.30

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APPENDIX A

SWITCHBOARD TESTING WITH KD-10 AND KD-11 RELAYS

External connections may be checked at the relay provided there is sufficient load current flow at a known power factor angle. Relay current should be at least $\frac{7}{T}$ amperes (1.2 amps when T = 5.8). This check is appropriate prior to commissioning the relay or when trouble shooting.

1.0 POTENTIAL CIRCUIT CHECK

Close the three relay potential switches numbered 7, 8, and 9, (Figure 19). The connection for the proper phase sequence will be indicated by a strong contact-opening torque. Closing torque will indicate reverse-phase sequence.

2.0 CURRENT VERIFICATION

To verify the proper current connections use the following procedure:

a. Set T = 5.8, S = 1 for maximum sensitivity. (Lower or higher taps may be used, provided currents exceeds $\frac{7}{T}$). Open current switches first for safety.

b. Read watts, vars and amperes.

c. Plot watts and vars on the diagram in Figure 27. Draw a line at the load angle determined by this plot. Designate this line as I_{REF}. See Figure 28 for example.

d. Perform the nine switching combinations in Table IV (page 26), recording the relay contact position for each combination. Actually only 6 combinations are needed to verify the currents, so that any group of three need not be used. This is important where the load angle falls too close to the zero torque line. If the indicated power-factor angle is within 3° of the test limit for any group of three tests, these should be ignored.

e. Verify the currents using the procedure illustrated in Table V (page 27). Here the “correct contact position” is determined by observing whether the I_{REF} line in figure 28 intersects the solid or the dashed part of circle. (For example, test 1b shows a solid circle indicating that the contact should close.) Next compare the actual contact positions to the correct ones.

f. If the contact positions are proper, the current connections are correct and the test is complete, otherwise proceed to identify the currents using the following procedure.

3.0 CURRENT IDENTIFICATION

If the verification check discloses incorrect current connections, the following procedure may be used to determine what is wrong. However, if one set of three switching combinations places the relay too close to the zero-torque line, use conventional techniques, instead, since identification requires all nine switching combinations.

a. Plot aI_{REF} and a^2I_{REF} at 120° angles from I_{REF}. See Figure 28 for example. These currents are related to the phase currents as shown in the following table:

Phase Receiving Current	I_{REF}	a^2I_{REF}	aI_{REF}
1	$I_{PH.A}$	$I_{PH.B}$	$I_{PH.C}$
2	$I_{PH.B}$	$I_{PH.C}$	$I_{PH.A}$
3	$I_{PH.C}$	$I_{PH.A}$	$I_{PH.B}$

b. Prepare Table VI (page 27) similar to Table V (page 27) using Figure 28 (page 56). For example, for test 1b the contacts were open. Such a result would occur if I_{REF} of the wrong polarity is actually flowing in the phase A circuits of the relay. This conclusion is drawn by noting that I_{REF} in Figure 28 intersects the solid part of the test 1b circle. This says that if $+I_{REF}$ is flowing the contacts would close. Since the contacts actually open, then $-I_{REF}$ could be flowing. similarly, for test 1b, $-a^2I_{REF}$ could be flowing, since the a^2I_{REF} line also intersects the solid part of the test 1b circle. By the process of elimination for each set of 3 tests, the actual current is identified. For example, in Table V (page 27), phase A receives $-I_{PH.A}$ whereas $+I_{PH.A}$ should be flowing. In phase B $+I_{PH.C}$ is flowing as shown in Figure 29. To extract this bit of information from Table V (page 27), use the above table relating the phase currents to I_{REF}, a^2I_{REF}.

NOTE: In Table V that a^2I_{REF} is flowing in the phase B circuits of the relay. The above table shows for this set of 3 tests that a $a^2I_{REF} = I_{PH.C}$.

c. Correct the external connections and then verify the currents.

Table IV:

SWITCHING COMBINATION		SWITCHING FOR CURRENT VERIFICATION AND IDENTIFICATION								
		Position of Switches Numbered:							Unit Which Should be Observed	Phase Receiving Current
		Voltage Switch			Current Switch (Blank indicates open switch)					
		V_{AN} 7	V_{BN} 8	V_{CN} 9	I_A 12, 13	I_B 14, 15	I_C 16, 17	I_A 18, 19 (3)		
1	a	Open & jump sw. jaw to 9	Closed	Closed			Closed		- & †	C
	b				‡ Closed			Closed	- & 3	A
2	a	Closed	Open & jump sw. jaw to 7	Closed	Closed			Closed	- & 3	A
	b					Closed			- & †	B
3	a	Closed	Closed	Open & jump sw. jaw to 8		Closed			- & †	B
	b						Closed		- & †	C
4		Closed	Closed	Open & jump sw. jaw to 7	‡ Closed			Closed	- & 3	A
5		Open & jump sw. jaw to 8	Closed	Closed		Closed			- & †	B
6		Closed	Open & jump sw. jaw to 9	Closed			Closed		- & †	C

† Block 3 Unit Open.

‡ If current is over 5 amps.

Table V:
VERIFICATION EXAMPLE USING ASSUMED LOADING OF FIGURE 29

PHASE TO BE VERIFIED	SWITCHING COMBINATION	CORRECT CONTACT POSITION	ACTUAL CONTACT POSITION	
			IF WIRING IS CORRECT	EXAMPLE WITH INCORRECT WIRING
A	1b	C	C	O
	2a	C	C	O
	4	O	O	C
B	2b	C	C	C
	3a	C	C	O
	5	O	O	C
C	3b	C	C	O
	1a	C	C	O
	6	O	O	O

Table VI:
IDENTIFICATION EXAMPLE USING ASSUMED LOADING OF FIGURE 29

I_{REF} PHASE RECEIVING CURRENT	SWITCHING COMBINATION	EXAMPLE OF CONTACT POSITION	CURRENT & POLARITY WHICH CAN PRODUCE OBSERVED CONTACT POSITION		
			I_{REF}	a^2I_{REF}	aI_{REF}
A	1b 2a 4	O O C	– – –	– + +	+ + –
B	2b 3a 5	C O C	+ – –	+ + +	– + –
C	3b 1a 6	O O O	– – +	– + –	+ + +

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APPENDIX B

THE KD COMPENSATOR DISTANCE RELAYS CALIBRATION AND MAINTENANCE PROCEDURES

A calibration and maintenance program should involve two steps: 1) a receiving acceptance check and 2) a routine (periodic) maintenance program. These two steps are outlined below.

1.0 RECEIVING ACCEPTANCE

Received relays should be subjected to the checks outline in the applicable I.L. These checks will insure that there is no shipping damage and the relay has been received in the same calibrated condition as it left the factory. They will insure that set-up procedures such as removing contact blocking has been accomplished. A receiving acceptance check should include the following steps:

a. Perform all of the mechanical and electrical tests listed in the receiving acceptance section of the applicable I.L., include the maximum torque angle test, even if it is not called for in some I.L.'s.

b. Follow the appropriate test procedures outlined in Instruction Leaflets covering the KDAR Field Test Unit. It is suggested that all dial test readings in each test be recorded for future reference. This information will be very helpful in recognizing possible drift or electrical characteristics.

c. If the settings to be applied to the relay when it is installed are known, the relay should be set to these settings and checked with the field units as noted in step 2 above. A record for future reference should be taken. The relay test values using the KDAR test unit should check to be within 7 percent of the relay settings.

2.0 ROUTINE MAINTENANCE

The relay should be checked periodically at time intervals dictated by pervious experience and practices. ABB recommends the time interval between checks be a maximum of two years. Routine maintenance should include at least the following steps.

a. Repeat step 2 and 3 under **RECEIVING ACCEPTANCE** and record test results.

b. Compare test results with pervious results. If any test values deviate from previous checks by more than 5 percent, recheck relay performance in line with the receiving acceptance checks outlined above step 1.

c. Retain records of test results on each particular relay. During each routine maintenance, the records should be analyzed to determine if there is any evidence of drift; i.e., continued change in characteristic in the same direction. Evidence of drift should be traced to the particular element involved, usually a capacitor or resistor and this element replaced.

d. Some of the more common component problems may be detected as follows:

With the relay mounted on a panel and energized by station C, T's & P. T's open all trip circuits and all current switch positions 12, 13, 14, 15, 16, 17, 18, 19, and phase C voltage switches (terminal 9), and if applicable, an additional switch position on the separately energized 3 unit. Check the internal schematic for your particular relay. Jumper terminal 7 to terminal 9 and to any other applicable switch normally connected to phase C, on the relay side (upper half of the switch). The contacts of both operating units should stay open. If the 3-phase unit contact closes, it indicates misadjustment of resistor, R_{3A}, or potentiometer, P_{3A} (most common cause), or defective capacitor, C_{3C}. Follow the instructions for trouble shooting in Section 3.3. "**SUGGESTED PROCEDURE FOR DETECTING AND REPLACING DEFECTIVE C_{3C} CAPACITOR FOR KD-4, KD-5 AND KD-10 RELAYS**" (page 31), and the proper instruction leaflet for KD/KD-1, and KD-10/KD-11 relays.

If phase-to-phase unit closes, recheck for:

- KD/KD-1 relays — R_{MA} & R_{MC}-Calibration
- KD-4/KD-41 & KD-5 — R_{AC}-Calibration
- KD-10/KD-11 — X_{LAC}-Adjustment

3.0 CALIBRATION AND TROUBLESHOOTING HINTS

3.1 CALIBRATION OF THE RELAY FOR MAXIMUM TORQUE ANGLE

Experience has shown that calibration of the relay for maximum torque angle is the procedure most susceptible to error. Two potential sources of error most common are:

a. Instrumentation errors: Be sure of the accuracy of calibration of all instruments and phase-shifters used. Instruments should be chosen and ranges selected so that readings are taken with the instrument reading in the top third of the scale.

When a phase-shifter is used, attention should be paid to voltage and current settings that change as the angle is varied. To avoid inaccuracies due to this effect, check the voltage and current settings when contact operation indicates that maximum torque angle check point has been reached.

b. Failure or miscalibration of components not connected with angle adjustment: To distinguish between the two sources of error it is recommended a compensator nulling test be performed as follows.

3.1.1 KD-4, 41, 5, 10, and 11 Relays: Phase-to-Phase Unit (T_{AB} and T_{BC} Compensators) Maximum Sensitivity Angle

a. Use “PH-PH-1-2 Phase” test connection for T_{AB} compensator, and “PH-PH-2-3” test connection for T_{BC} compensator. Refer to Figure 26 (page 55).

b. Measure voltage across C_{2A} for T_{AB} and across C_{2C} for T_{BC}.

c. Set current equal to: $\dfrac{V_{IF2F}}{2X\ Relay\ Setting}$

The current should be high enough to provide an accurate phase angle meter reading, or any convenient value if a phase-shifter is used for direct angle reading.

d. Set the phase-shifter for the desired maximum torque angle value. NOTE THE VOLTAGE.

e. Vary the phase angle in both directions of the set value, to see that a low voltage (below one volt) is obtained at the maximum torque angle setting. If within two degrees, it can be left undisturbed. If minimum voltage is obtained at some other angle, readjust phase-shifting resistor or potentiometer at the desired angle.

3.1.2 KD and KD-1 Relays: Phase-to-Phase Unit (T_{AB} and T_{BC} Compensators) Maximum Sensitivity Angle

Follow procedure above except:

a. For T_A compensator, use connection #2, omit voltage connection to terminal 9, disconnect L_A-lead, insert voltmeter to measure open circuit voltage and use twice the current value obtained for KD-10 tests. Follow procedure outline above except adjust R_{2A} when required.

b. For T_B compensator, use procedure outline above, except use #3 connection and adjust R_{2B} when required.

c. For T_C compensator, use connection #4, omit voltage connection to terminal 7, disconnect L_C-lead, and adjust R_{2C} when required as per part 1.

3.2 THREE-PHASE UNIT: (T COMPENSATOR OF ALL KD TYPE RELAYS)

a. Use connection #1.

b. Measure voltage across C3A.

c. Set the current equal to: $\dfrac{V_{1F2F}}{1.5\text{ Relay Setting}}$

The current should be high enough to provide an accurate phase meter reading, or any convenient value if a phase-shifter is used for direct angle reading.

d. Set the phase-shifter for the desired maximum torque angle value.

e. Vary phase angle in both directions of the set value, to see that a low voltage (below 1 volt) is obtained at the maximum torque angle setting. If minimum voltage is within 2 degrees, do not readjust. If the minimum voltage is obtained at some other angle readjust phase-shifting resistor or potentiometer at the desired angle.