TABLE 5 CONT'D

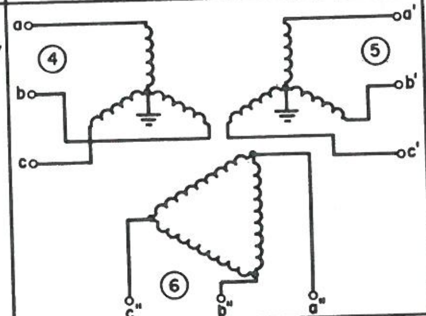
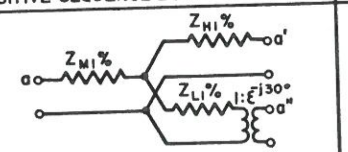
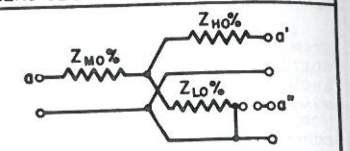
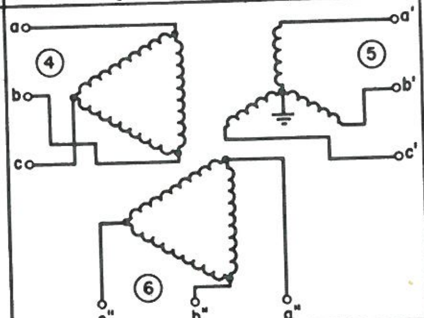
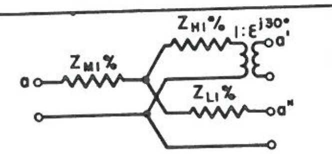
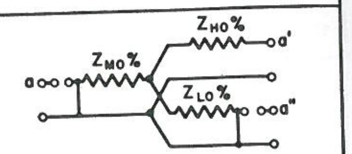
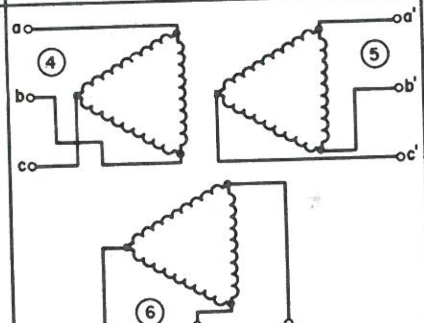
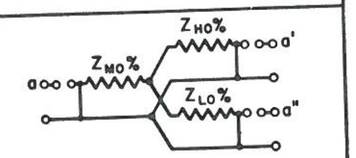
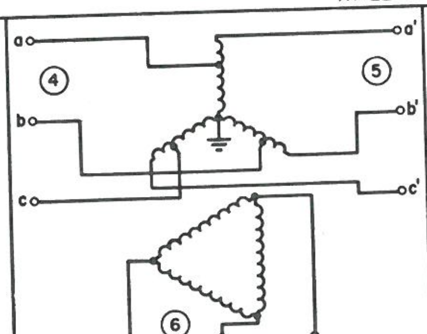
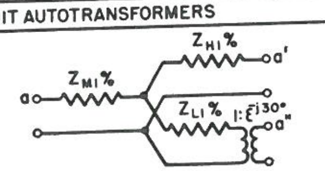
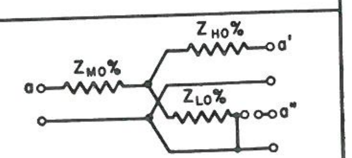
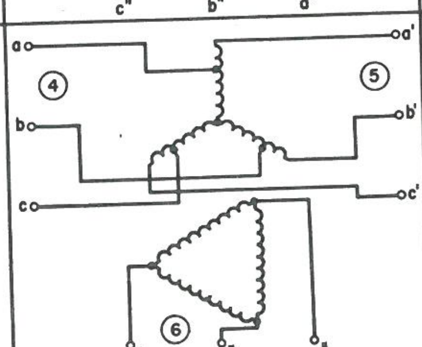
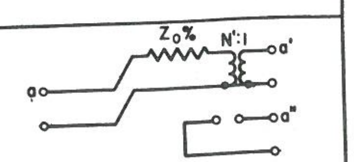
DESCRIPTION	DIAGRAM OF CONNECTIONS	POSITIVE-SEQUENCE EQUIVALENT CIRCUIT	ZERO SEQUENCE EQUIVALENT CIRCUIT
THREE-CIRCUIT TRANSFORMERS (CONT'D.)			
C-3 STAR/STAR/DELTA SOLIDLY GROUNDED NEUTRALS		 $Z_{MI}\% = \frac{1}{2}\left[Z_{45}\% + Z_{46}\% - \frac{U_4}{U_5} Z_{56}\%\right]$ $Z_{LI}\% = \frac{1}{2}\left[Z_{46}\% + \frac{U_4}{U_5} Z_{56}\% - Z_{45}\%\right]$ $Z_{HI}\% = \frac{1}{2}\left[\frac{U_4}{U_5} Z_{56}\% + Z_{45}\% - Z_{46}\%\right]$	 $Z_{MO}\% = Z_{MI}\%$ $Z_{LO}\% = Z_{LI}\%$ $Z_{HO}\% = Z_{HI}\%$
C-6 DELTA/STAR/DELTA SOLIDLY GROUNDED NEUTRAL		 $Z_{MI}\% = \frac{1}{2}\left[Z_{45}\% + Z_{46}\% - \frac{U_4}{U_5} Z_{56}\%\right]$ $Z_{LI}\% = \frac{1}{2}\left[Z_{46}\% + \frac{U_4}{U_5} Z_{56}\% - Z_{45}\%\right]$ $Z_{HI}\% = \frac{1}{2}\left[\frac{U_4}{U_5} Z_{56}\% + Z_{45}\% - Z_{46}\%\right]$	 $Z_{MO}\% = Z_{MI}\%$ $Z_{LO}\% = Z_{LI}\%$ $Z_{HO}\% = Z_{HI}\%$
C-7 DELTA/DELTA/DELTA		SAME AS C-1	 $Z_{MO}\% = Z_{MI}\%$ $Z_{LO}\% = Z_{LI}\%$ $Z_{HO}\% = Z_{HI}\%$
THREE-CIRCUIT AUTOTRANSFORMERS			
D-1 STAR/STAR/DELTA SOLIDLY GROUNDED NEUTRAL		 $Z_{MI}\% = \frac{1}{2}\left[Z_{45}\% + Z_{46}\% - \frac{U_4}{U_5} Z_{56}\%\right]$ $Z_{LI}\% = \frac{1}{2}\left[Z_{46}\% + \frac{U_4}{U_5} Z_{56}\% - Z_{45}\%\right]$ $Z_{HI}\% = \frac{1}{2}\left[\frac{U_4}{U_5} Z_{56}\% + Z_{45}\% - Z_{46}\%\right]$	 $Z_{MO}\% = Z_{MI}\%$ $Z_{LO}\% = Z_{LI}\%$ $Z_{HO}\% = Z_{HI}\%$
D-2 STAR/STAR/DELTA UNGROUNDED NEUTRAL		SAME AS D-1	 $N' = \frac{E_5}{E_4}$ $Z_0\% = N'(N'-1)\left[\frac{U_4}{U_5} Z_{56}\% - \frac{Z_{46}\%}{N'} + \frac{Z_{45}\%}{N'-1}\right]$

TABLE 6—CONVERTING OHMIC IMPEDANCES TO A WINDING BASE

Case	Conversion	Case	Conversion
A-1, A-2, A-3, A-4, A-5	$Z_{PS} = Z_{45}$ (a)	C-9	(g)
A-6, A-7	$Z_{PS} = 3Z_{45}$	D-1	Obtain Z_{MI}, Z_{HI} and Z_{LI} as for Case C-8.
A-8	(b)	D-2	Obtain Z_{MI}, Z_{HI} and Z_{LI} as for Case C-8. $Z_{ST} = N'(N'-1)\left[\frac{Z_{56}}{(N')^2} - \frac{Z_{46}}{N'} + \frac{Z_{45}}{N'-1}\right]$
A-9	$Z_1 = Z_{45}$ (c) $Z_{ST} = Z_0'$ (d)		
A-10	$Z_1 = Z_{45}$ (c)(e)		
B-1, B-2, B-3	$Z_{PS} = \frac{N^2}{(N-1)^2} Z_{45}$ (a)	D-3	$Z_{PS} = Z_{TS} = \frac{1}{2}Z_{46} + 3Z_{45}$ $Z_{PT} = Z_{46}$
B-4, B-5	$Z_1 = Z_{45}$ (a)(c)	D-4	(g)
C-1, C-2, C-3, C-4, C-5	$Z_{PS} = Z_{45}$ $Z_{PT} = Z_{46}$ $Z_{ST} = Z_{56}$	E-7	$Z_1 = Z_{45}$ $Z_{PS} = \left(\frac{N}{N-1}\right)^2 Z_{45}$ $Z_{PT} = Z_{46}$ $Z_{ST} = N(N-1)\left[\frac{Z_{56}}{N^2} - \frac{Z_{46}}{N} + \frac{Z_{45}}{N-1}\right]$
C-6	$Z_{PS} = 3Z_{45}$ $Z_{PT} = 3Z_{46}$ $Z_{ST} = Z_{56}$		
C-7	$Z_{PS} = 3Z_{45}$ $Z_{PT} = 3Z_{46}$ $Z_{ST} = 3Z_{56}$	E-8	See E-7, above
C-8	$Z_{MI} = \frac{1}{2}\left[Z_{45} + Z_{46} - \left(\frac{E_4}{E_5}\right)^2 Z_{56}\right]$ $Z_{HI} = \frac{1}{2}\left[Z_{45} + \left(\frac{E_4}{E_5}\right)^2 Z_{56} - Z_{46}\right]$ $Z_{LI} = \frac{1}{2}\left[Z_{46} + \left(\frac{E_4}{E_5}\right)^2 Z_{56} - Z_{45}\right]$ $Z_{ST} = Z_{56}$ (f)	E-9 to G-6	See note (h)

a In the case of three-phase core-form transformers, the complete zero-sequence equivalent circuit includes impedances that are a function of the zero-sequence exciting characteristics of the transformer. These impedances are therefore affected by the magnitude of the zero-sequence voltage applied to the transformer windings during fault conditions. In any accurate calculation of zero-sequence currents or voltages it is necessary to represent these impedances by a saturation curve rather than by a fixed impedance, which results in a step-by-step analytical solution. In cases where the three-phase core-form transformer has a delta tertiary, or where other ground sources are present, satisfactory results can be obtained by neglecting the zero-sequence exciting impedances of the transformer. If this procedure is followed the transformer is treated as three single-phase units or a three-phase shell-form unit.

b The rating of a zig-zag grounding bank is normally expressed in terms of line-to-line voltage and neutral amperes. In the case of standard grounding transformers which have 100 percent impedance,

$$Z_{PS} = \frac{\sqrt{3}E}{I_n}, \text{ where}$$

E = line-to-line voltage in kv.

I_n = neutral current in amperes.

When a zig-zag transformer has less than 100 percent impedance, Z_{PS} must be modified accordingly.

c In many cases it is simpler to obtain the sequence impedances directly from the circuit impedances without converting the latter to a circuit base.

d When a transformer has a zig-zag winding the manufacturer should furnish the zero-sequence impedance as viewed from the zig-zag side.

e Obtain Z_{ST} as in Case A-9 for a solidly grounded transformer.

f The manufacturer should furnish the zero-sequence impedance of the transformer as viewed from the zig-zag side. Z_{PV} is then equal to this impedance expressed in ohms.

g Refer to manufacturer.

h In those cases involving series transformers, the exciting transformer and the series transformer should be treated as separate units when deriving the basic impedance data. To obtain the conversion factors for the exciting transformer, refer to the two or three-winding transformer case employing the same connections.

In furnishing impedance data on a series transformer, the manufacturer will usually treat the unit as a simple two-winding transformer. The impedance is usually expressed in percent on a kva base corresponding to the parts used in the series transformer. The percent impedance is based on the voltage rating of the winding to be connected in the main power circuit. For example, in Case E-9, the rated voltage of the V winding is used in obtaining the percent impedance. This impedance is converted to ohms as follows:

$$Z_{VW} = \frac{10E_V^2 Z_{VW}\%}{U_V}, \text{ where}$$

E_V = kv rating of the V winding (actual winding voltage in the case of single-phase series transformers and $\sqrt{3}$ times winding voltage in the case of three-phase series transformers).

U_V = kva rating of the series transformer (per-phase rating for single-phase transformers and three-phase rating for three-phase transformers).