APPENDIX 1

THE PER UNIT EQUATIONS OF AN EQUIVALENT DC TERMINAL

Let $P_{acbase}$, $V_{acbase}$ and $I_{acbase}$ be the base power, base voltage and base current at the valve side windings of each converter transformer with the base voltage chosen as the rated rms line-to-line voltage.

Let $P_{dcbase}$, the dc power base of the equivalent dc terminal be same as $P_{acbase}$. Then we have

$$P_{dcbase} = P_{acbase} = P_{base}$$

$$I_{acbase} = \frac{P_{base}}{\sqrt{3} V_{acbase}} \quad (A1.1)$$

$$Z_{acbase} = \frac{V_{acbase}}{\sqrt{3} I_{acbase}} \quad (A1.2)$$

Let the dc base voltage of the dc terminal be chosen as

$$V_{dcbase} = K V_{acbase} \quad (A1.3)$$

where

$$K = \frac{3/2}{n_b} \quad (A1.4)$$

Then,

$$I_{dcbase} = \frac{\sqrt{3}}{K} I_{acbase} \quad (A1.5)$$

$$R_{dcbase} = K^2 Z_{acbase} \quad (A1.6)$$
Equivalent commutation resistance $R_{cb}$ of one bridge in ohms is

$$R_{cb} = \frac{3}{\pi} X_{cb} \text{ ohms}$$

Since all the $n_b$ bridges are in series on the dc side, the total equivalent commutation resistance in ohms is

$$R_c = n_b \frac{3}{\pi} X_{cb} \text{ ohms}$$

Total equivalent commutation resistance in per unit is,

$$R_{cpu} = \frac{R_c \text{ (ohms)}}{R_{dcbase}} = \frac{n_b (3/\pi) X_{cb}}{K^2 Z_{acbase}}$$

Using equation (A1.4),

$$R_{cpu} = \frac{1}{\sqrt{2K}} X_{cpu}$$

Total dc voltage for $n_b$ bridges in series using equation (2.5) is

$$V_d = n_b \left[ \frac{3/2}{\pi} t V_t \cos \theta - I_d R_{cb} \right]$$

$$V_{dpu} V_{dcbase} = n_b \frac{3/2}{\pi} t V_{tpu} \frac{1}{t_n} V_{acbase} \cos \theta - n_b I_{dpu} I_{dcbase} \frac{3}{\pi} X_{cb}$$

where $t_n$ is the nominal turns ratio of each converter transformer.
\[ V_{dpu} = a \frac{v_{tpu}}{t} \cos \theta - I_{dpu} R_{cpu} \quad (A1.7) \]

where \( a = \frac{t}{t_n} \) is the off-nominal tap ratio of converter transformer.

From equation (2.6), the dc voltage for \( n_b \) bridges is also given by

\[
V_d = n_b \frac{3/2}{\pi} t v_t \cos \phi
\]

\[
V_{dpu} V_{dcbase} = n_b \frac{3/2}{\pi} t \frac{1}{v_{tpu}} t_n v_{acbase} \cos \phi
\]

\[ V_{dpu} = a v_{tpu} \cos \phi \quad (A1.8) \]

From equations (2.7) and (2.8)

\[ P_{dpu} = V_{dpu} I_{dpu} \quad (A1.9) \]

\[ Q_{dpu} = \rho P_{dpu} \tan \phi \quad (A1.10) \]

From equations (A1.7) to (A1.10) and dropping suffix pu for simplicity and adding suffix k to denote the \( k^{th} \) terminal the per unit relations for the \( k^{th} \) terminal are

\[ V_{dk} = a_k v_{tk} \cos \theta_k - I_{dk} R_{ck} \quad (A1.11) \]

\[ V_{dk} = a_k v_{tk} \cos \phi_k \quad (A1.12) \]

\[ P_{dk} = V_{dk} I_{dk} \quad (A1.13) \]

\[ Q_{dk} = \rho_k P_{dk} \tan \phi_k \quad (A1.14) \]