APPENDIX C THE ELECTRICAL DISTANCES a, b AND c

This appendix computes the electrical distances a, b and c.

C.1 APPROACH USED TO OBTAIN a, b AND c

To compute a the line resistance and shunts are omitted from the tie line. The improved two generator model (Chapter 3, figure 3.2) then simplifies into the model shown in figure C.1. Figure C.2 is the load flow of network shown in figure C.1.

To ensure the power angle, δ_{POOL}, with which $\boldsymbol{V_{MPU}}$ leads $\boldsymbol{V_{KOEBG4}}$ is non-zero, the Koeberg generator is made to motor.

The electrical distance a is the distance by which Perseus is electrically removed from $\boldsymbol{V_{MPU}}$.

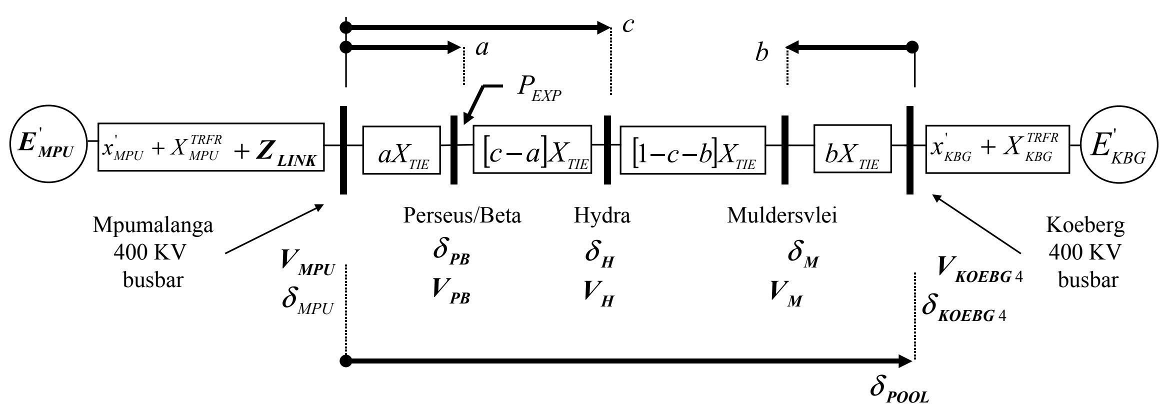

FIGURE C.1 Power angles and voltages used when computing a, b and c

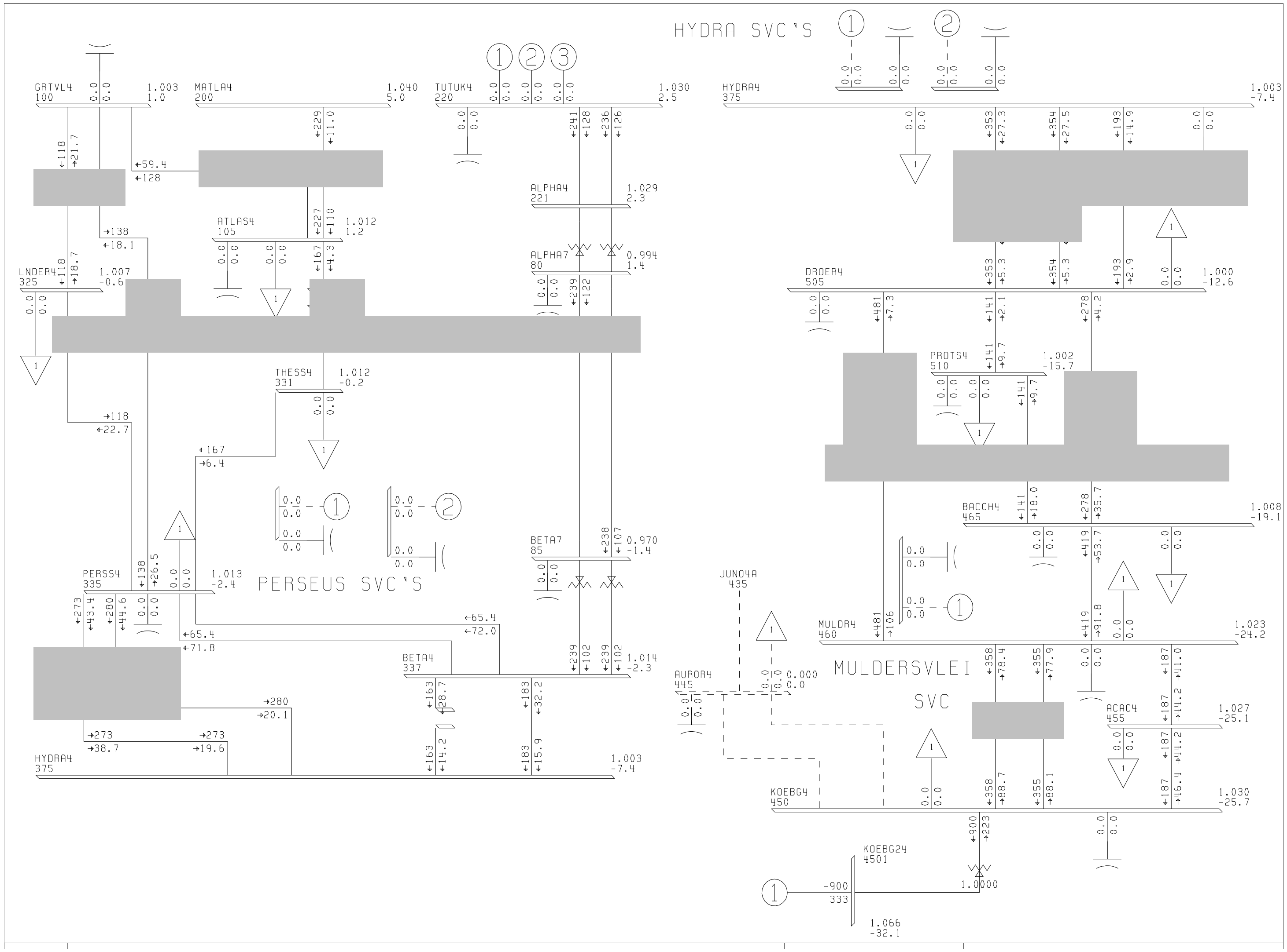

FIGURE C.2 Steady state load flow when the loads, line charging, line resistance and voltage regulating shunts are omitted from the detailed network model shown in figure 3.3

Most of the parameters and vectors shown in figure C.1 are described in Chapter 3, section 3.4. The below listed parameters and vectors are not described. We note X_{TIE} is the reactance of the Mpumalanga-to-Western-Cape tie line when all the shunts and line resistance are omitted; $\boldsymbol{V_{MPU}}$ is the voltage vector that represents the southern border of the Mpumalanga generation pool; δ_{MPU} is the power angle of $\boldsymbol{V_{MPU}}$; $\boldsymbol{V_{PB}}$ is the Perseus/Beta voltage vector (electrically Perseus and Beta are the same busbar); $\delta_{\boldsymbol{MPU}} - \delta_{\boldsymbol{PB}}$ is the power angle with which the southern border of Mpumalanga leads $\boldsymbol{V_{PB}}$; $\boldsymbol{V_H}$ is the Hydra voltage vector; $\delta_{\boldsymbol{MPU}} - \delta_{\boldsymbol{H}}$ is the power angle with which the southern border of Mpumalanga leads $\boldsymbol{V_H}$; $\boldsymbol{V_M}$ is the Muldersvlei voltage vector and $\delta_{\boldsymbol{MPU}} - \delta_{\boldsymbol{M}}$ is the power angle with which the southern border of Mpumalanga leads $\boldsymbol{V_M}$.

The total impedance of the network can be described using a and $(1-a)$. The network associated with this modelling of the tie line is shown in figure C.3.

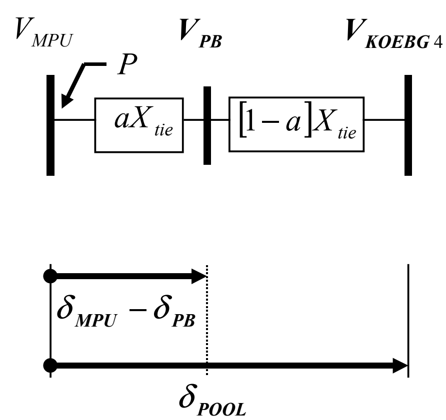

FIGURE C.3 Network used to obtain the electrical distance a

To clarify how a is computed using the network shown in figure C.3, we note Perseus and Beta are electrically the same busbar. Hence, the voltage, $|\boldsymbol{V_{PB}}|$, and power angle, $\delta_{\boldsymbol{PB}}$, of the Beta/Perseus busbar can be computed using:

$$\left|\boldsymbol{V_{PB}}\right| = \frac{\left|\boldsymbol{V_{PERSEUS}}\right| + \left|\boldsymbol{V_{BETA}}\right|}{2} \tag{C.1-a}$$

$$\delta_{\boldsymbol{PB}} = \frac{\delta_{\boldsymbol{PERSEUS}} + \delta_{\boldsymbol{BETA}}}{2} \tag{C.1-b}$$

Where $\left|\boldsymbol{V_{PERSS4}}\right|$ is the magnitude of the Perseus voltage; $\delta_{\boldsymbol{PERSS4}}$ is the power angle at Perseus; $\left|\boldsymbol{V_{BETA4}}\right|$ is the magnitude of the Beta voltage and $\delta_{\boldsymbol{BETA4}}$ is the power angle at Beta.

It follows from figure C.3 that the power, P, Mpumalanga exports to Koeberg can be computed using:

$$P = \frac{1}{X_{TIE}} \left|\boldsymbol{V_{MPU}}\right| \left|\boldsymbol{V_{KOEBG4}}\right| \sin\left(\delta_{\boldsymbol{pool}}\right) \tag{C.2}$$

P can also be computed using:

$$P = \frac{1}{aX_{TIE}} \left|\boldsymbol{V_{MPU}}\right| \left|\boldsymbol{V_{PB}}\right| \sin\left(\delta_{\boldsymbol{MPU}} - \delta_{\boldsymbol{PB}}\right) \tag{C.3}$$

When setting equation C.2 equal to equation C.3 we obtain:

$$\frac{1}{X_{TIE}} \left|\boldsymbol{V_{MPU}}\right| \left|\boldsymbol{V_{KOEBG4}}\right| \sin\left(\delta_{\boldsymbol{pool}}\right) = \frac{1}{aX_{TIE}} \left|\boldsymbol{V_{MPU}}\right| \left|\boldsymbol{V_{PB}}\right| \sin\left(\delta_{\boldsymbol{MPU}} - \delta_{\boldsymbol{PB}}\right)$$

$$\frac{\left|\boldsymbol{V_{KOEBG4}}\right|}{\left|\boldsymbol{V_{PB}}\right|} \times \frac{\sin\left(\delta_{\boldsymbol{pool}}\right)}{\sin\left(\delta_{\boldsymbol{MPU}} - \delta_{\boldsymbol{PB}}\right)} = \frac{1}{a}$$

$$a = \frac{\left|\boldsymbol{V_{PB}}\right|}{\left|\boldsymbol{V_{KOEBG4}}\right|} \times \frac{\sin\left(\delta_{\boldsymbol{MPU}} - \delta_{\boldsymbol{PB}}\right)}{\sin\left(\delta_{\boldsymbol{pool}}\right)} \tag{C.4}$$

To show how the power angle, $\delta_{\boldsymbol{POOL}}$, with which the southern border of the Mpumalanga power pool leads the high voltage busbar at Koeberg can be computed, we note Grootvlei, Atlas and Tutuka jointly form the southern border of the Mpumalanga power pool. Hence:

$$\begin{aligned}\delta_{POOL} &= \delta_{MPU} - \delta_{KOEBG4} \\ &= \left(\frac{\delta_{GRTVL4} + \delta_{ATLAS4} + \delta_{TUTUK4}}{3}\right) - \delta_{KOEBG4}\end{aligned} \tag{C.5}$$

Where δ_{GRTVL4} is the power angle at Grootvlei; δ_{ATLAS4} is the power angle at Atlas; δ_{TUTUK4} is the power angle at Tutuka and δ_{KOEBG4} is the power angle of the 400 kV Koeberg busbar.

It follows from equation C.1-b and equation C.5 that the power angle, $\delta_{MPU} - \delta_{PB}$, by which V_{MPU} leads V_{PB} is:

$$\delta_{MPU} - \delta_{PB} = \left(\frac{\delta_{GRTVL4} + \delta_{ATLAS4} + \delta_{TUTUK4}}{3}\right) - \left(\frac{\delta_{PERSS4} + \delta_{BETA4}}{2}\right) \tag{C.6}$$

Equation C.4 can also be used to determine $(1-b)$ and c.

To compute $(1-b)$, $|V_{PB}|$ and δ_{PB} are replaced with $|V_M|$ and δ_M. $|V_M|$ is the magnitude of the Muldersvlei voltage and δ_M is the angle by which V_M leads V_{KOEBG4}.

To compute c, $|V_{PB}|$ and δ_{PB} are replaced with $|V_H|$ and δ_H. $|V_H|$ is the magnitude of the Hydra voltage and δ_H is the angle by which V_{MPU} leads V_H.

$|V_{KOEBG4}|$, δ_{KOEBG4}, $|V_{PERSS4}|$, δ_{PERSS4}, $|V_{BETA4}|$, δ_{BETA4}, δ_{GRTVL4}, δ_{ATLAS4}, δ_{TUTUK4}, $|V_M| = |V_{MULDR4}|$, $\delta_M = \delta_{MULDR4}$, $|V_H| = |V_{HYDRA4}|$ and $\delta_H = \delta_{HYDRA4}$ are obtained from the load flow shown in figure C.2.

C.2 OBTAINING a, b AND c

The equations used to compute a, b and c require as input data the values $\left|V_{KOEBG4}\right|$, δ_{MPU} and δ_{POOL} attain in the network shown in figure C.2.

δ_{POOL} can be computed using (equation C.5):

$$\delta_{POOL} = \left(\frac{\delta_{GRTVL4} + \delta_{ATLAS4} + \delta_{TUTUK4}}{3}\right) - \delta_{KOEBG4}$$

$$= \delta_{MPU} - \delta_{KOEBG4} \tag{C.7}$$

For the network shown in figure C.2:

$$\delta_{POOL} = \frac{\left(\delta_{GRTVL4} + \delta_{ATLAS4} + \delta_{TUTUK4}\right)}{3} - \delta_{KOEBG4}$$

$$= \frac{\left(1.0^\circ + 1.2^\circ + 2.5^\circ\right)}{3} - \left(-25.7^\circ\right)$$

$$\approx 27.3^\circ \tag{C.8}$$

It follows from equation C.7 that:

$$\delta_{MPU} \approx 1.6^\circ \tag{C.9}$$

For the network shown in figure C.2:

$$\left|V_{KOEBG4}\right| = 1.03 \tag{C.10}$$

The electrical distance a can be computed using (equation C.4):

$$a = \frac{|V_{PB}|}{|V_{KOEBG4}|} \times \frac{\sin(\delta_{MPU} - \delta_{PB})}{\sin(\delta_{POOL})}$$

$|V_{PB}|$ and $\delta_{MPU} - \delta_{PB}$ can be computed using (equation C.1 and equation C.6):

$$\delta_{MPU} - \delta_{PB} = \left(\frac{\delta_{GRTVL4} + \delta_{ATLAS4} + \delta_{TUTUK4}}{3}\right) - \left(\frac{\delta_{PERSS4} + \delta_{BETA4}}{2}\right)$$

$$|V_{PB}| = \frac{|V_{PERSS4}| + |V_{BETA4}|}{2}$$

For the network shown in figure C.2:

$$|V_{PB}| = \frac{(|V_{PERSS4}| + |V_{BETA4}|)}{2}$$

$$= \frac{(1.013 + 1.014)}{2}$$

$$= 1.0135 \text{ p.u.} \qquad \text{(C.11-a)}$$

$$\delta_{PB} = \frac{(\delta_{PERSS4} + \delta_{BETA4})}{2}$$

$$= \frac{(-2.4^\circ - 2.3^\circ)}{2}$$

$$= -2.35^\circ \qquad \text{(C.11-b)}$$

The substitution of equation C.8, C.9, C.10 and C.11 into equation C.4 yields:

$$a = \frac{|V_{PB}|}{|V_{KOEBG4}|} \times \frac{\sin(\delta_{MPU} - \delta_{PB})}{\sin(\delta_{POOL})}$$

$$= \frac{1.0135}{1.03} \times \frac{\sin(1.6^\circ + 2.35^\circ)}{\sin(27.3^\circ)}$$

$$\approx 0.15 \tag{C.12}$$

From the previous paragraphs it follows the electrical distance $(1-b)$ can be computed using:

$$(1-b) = \frac{|\boldsymbol{V_M}|}{|\boldsymbol{V_{KOEBG4}}|} \times \frac{\sin(\delta_{MPU} - \delta_M)}{\sin(\delta_{POOL})} \tag{C.13}$$

For the network shown in figure C.2:

$$|\boldsymbol{V_M}| = 1.023 \text{ p.u.} \tag{C.14-a}$$

$$\delta_M = -24.2^\circ \tag{C.14-b}$$

The substitution of equation C.8, C.9, C.10 and C.14 into equation C.13 yields:

$$(1-b) = \frac{|\boldsymbol{V_M}|}{|\boldsymbol{V_{KOEBG4}}|} \times \frac{\sin(\delta_{MPU} - \delta_M)}{\sin(\delta_{POOL})}$$

$$= \frac{1.023}{1.03} \times \frac{\sin(1.6^\circ + 24.2^\circ)}{\sin(27.3^\circ)}$$

$$\approx 0.94$$

$$b \approx 0.06 \tag{C.15}$$

From the previous paragraphs it follows the electrical distance c can be computed using:

$$c = \frac{|\boldsymbol{V_H}|}{|\boldsymbol{V_{KOEBG4}}|} \times \frac{\sin(\delta_{MPU} - \delta_H)}{\sin(\delta_{POOL})} \tag{C.16}$$

For the network shown in figure C.2:

$$|\boldsymbol{V_H}| = 1.003 \text{ p.u.} \tag{C.17-a}$$

$$\delta_{\boldsymbol{H}} = -7.4^{\circ} \tag{C.17-b}$$

The substitution of equation C.8, C.9, C.10 and C.17 into equation C.16 yields:

$$c = \frac{|\boldsymbol{V_H}|}{|\boldsymbol{V_{KOEBG4}}|} \times \frac{\sin(\delta_{\boldsymbol{MPU}} - \delta_{\boldsymbol{H}})}{\sin(\delta_{\boldsymbol{POOL}})}$$

$$= \frac{1.003}{1.03} \times \frac{\sin(1.6^{\circ} + 7.4^{\circ})}{\sin(27.3^{\circ})}$$

$$\approx 0.33 \tag{C.18}$$