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APPENDIX E COMPUTING THE DEMAND THE MPUMALANGA LOAD HAS

The appendix computes the MW, P_{PP-L}, and the MVAR, Q_{PP-L}, demand of the Mpumalanga load, $\boldsymbol{Y_{PP-L}}$, shown in Chapter 3, figure 3.20.

To compute P_{PP-L} and Q_{PP-L} the MW and MVAR demand of the Mpumalanga load shown in Chapter 3, figure 3.22 is solved.

It is assumed the Mpumalanga load shown in Chapter 3, figure 3.20 has the same MW and MVAR demand as the Mpumalanga load shown in Chapter 3, figure 3.22. This assumption is reasonable since no load is associated with the Secondary Pool (Chapter 3, figure 3.22)

E.1 ACTIVE DEMAND THE MPUMALANGA LOAD HAS

To clarify how P_{PP-L} is computed we note, the Primary Pool exports power to the Perseus/Beta busbar using the Grootvlei/Atlas-to-Perseus/Beta network.

In the simplified network model (Chapter 3, figure 3.8), Grootvlei exports $1\ 836 = (833 + 1\ 003)$ MW to the Perseus/Beta busbar. Atlas exports $1\ 085$ MW to the Perseus/Beta busbar. Therefore, the power, P_{GA}, Grootvlei/Atlas exports to Perseus/Beta is:

$$P_{GA} = 1\ 836 + 1\ 085 \text{ MW.}$$

$$= 2\ 921 \text{ MW.} \qquad \text{(E.1-a)}$$

When we subtract $P_{GA} = 2\ 921$ MW from the power, P_{PP}, generated in the Primary Pool we obtain the power, P, consumed north of Grootvlei/Atlas. The

demand of $2\ 921$ MW includes the Atlas infeed of -162 MW (Chapter 3, figure 3.8). $P_{PP} = 23\ 052$ MW (equation E.5). Hence:

$$P = 23\ 052 - 2\ 921 \text{ MW.}$$

$$= 20\ 131 \text{ MW.} \qquad \text{(E.1-b)}$$

Neither the load nor the shunt capacitor located at Atlas is part of the Mpumalanga load. Therefore, to compute P_{PP-L} the Atlas infeed must be subtracted from P. Hence:

$$P_{PP-L} = 20\ 131 - (-162) \text{ MW.}$$

$$= 20\ 293 \text{ MW.} \qquad \text{(E.1-c)}$$

The MW demand of the Mpumalanga load, expressed as a demand at nominal voltage, is:

$$P_{PP-L} = 20\ 293 \times \frac{1}{(1.0235)^2} \text{ MW.}$$

$$\approx 19\ 372 \text{ MW.} \qquad \text{(E.1-d)}$$

Where $\left|V_{PP}^{HV}\right| = 1.0235$ p.u.

Chapter 3, section 3.5.2 explains the formula used.

To clarify the value used for $\left|\boldsymbol{V}_{\boldsymbol{PP}}^{\boldsymbol{HV}}\right|$ we note, Matla is the northern border and Arnot the southern border of the Primary Pool. Hence, $\left|\boldsymbol{V}_{\boldsymbol{PP}}^{\boldsymbol{HV}}\right|$ is:

$$\left|\boldsymbol{V}_{\boldsymbol{PP}}^{\boldsymbol{HV}}\right| = \frac{\left|\boldsymbol{V}_{\boldsymbol{MATLA4}}\right| + \left|\boldsymbol{V}_{\boldsymbol{ARNOT4}}\right|}{2} \qquad \text{(E.2-a)}$$

The values $|V_{MATLA4}|$ and $|V_{ARNOT4}|$ obtain in the simplified network model are $|V_{MATLA4}| = 1.025$ p.u. and $|V_{ARNOT4}| = 1.022$ p.u. Hence,

$$\left|V_{PP}^{HV}\right| = \frac{|1.025| + |1.022|}{2} \text{ p.u.}$$

$$= 1.0235 \text{ p.u.} \qquad \text{(E.2-b)}$$

E.2 REACTIVE DEMAND THE MPUMALANGA LOAD HAS

The power factor the Mpumalanga generators operate at during system peak is approximately 0.98. Hence, Q_{PP-L} is tuned so that the generator of the Primary Pool operates at a 0.98 power factor.

The operation at a 0.98 power factor is realised for the case where the Primary Pool generator controls $|V_{MPU}|$ to achieve 1.001 p.u. (Chapter 3, equation 3.20-a).

To allow tuning Q_{PP-L} the parameters of the two generator model of the Mpumalanga generation pool (Chapter 3, figure 3.22) should be known. The reason is Q_{PP-L} is tuned using a network that includes the mentioned two generator model – refer to figure E.3.

Base transformation is used to adapt the parameters of a typical 750 MVA generator and associated generator transformer to realise the Primary and Secondary Pools. The networks shown in figure E.1 and figure E.2 are then obtained

A typical 750 MVA generator is used since the majority of generators found in the Mpumalanga generation pool are 750 MVA. The parameters of the typical 750 MVA generator and associated generator transformer are obtained from the Eskom database.

The remainder of this section computes the parameters listed in figure E.1 and figure E.2, and obtains the MVAR demand for Q_{PP-L}.

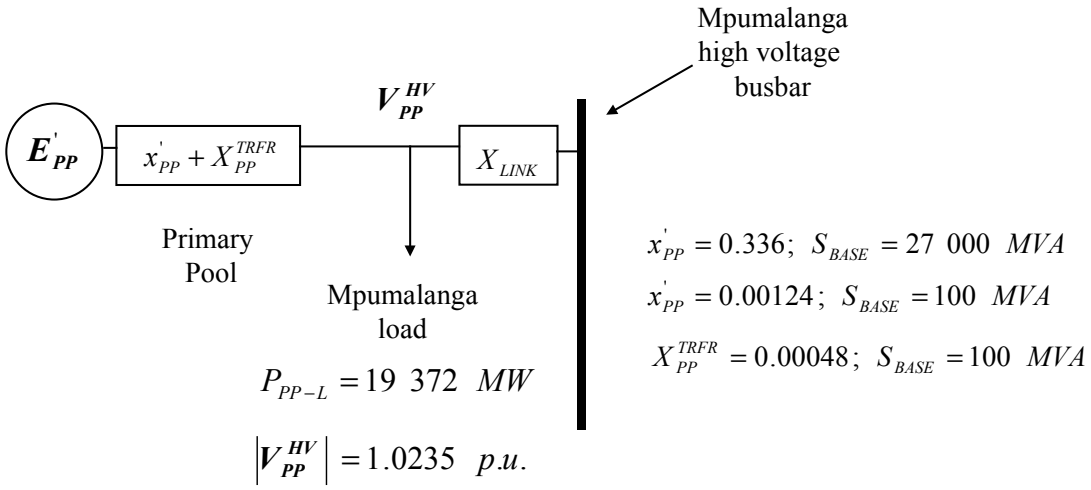


FIGURE E.1 Parameters of the electric circuit used to model the Primary Pool

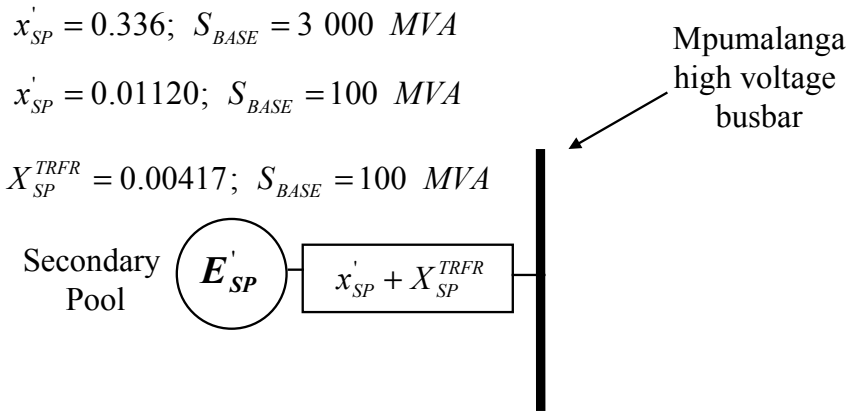


FIGURE E.2 Parameters of the Secondary Pool generator

E.2.1 Computing x'_{PP}, X_{PP}^{TRFR}, x'_{SP} and X_{SP}^{TRFR}

E.2.1.1 Computing the base MVA

PSS/E expresses the generator parameters on the generator base MVA.

To compute the base MVA of the Primary and Secondary Pools we note, the power generated in the simplified network model (Chapter 3, figure 3.8) is equal to $26\ 118$ MW. Except for Koeberg, Tutuka and Kendal all the power stations contributing towards this $26\ 118$ MW are located in the Primary Pool. Hence, the power, P_{PP}, generated in the Primary Pool can be computed using:

$$P_{PP} = 26\ 118 - \left(P_{SP} + P_{KBG}\right) \text{ MW.} \tag{E.3}$$

Where P_{SP} is the power generated in the Secondary Pool – i.e. the power the Secondary Pool exports to Perseus/Beta; and P_{KBG} is the power generated by Koeberg.

The Secondary Pool uses the Tutuka-Alpha lines to export power to Perseus/Beta. In the simplified network a total of $2\ 616 = \left(1\ 320 + 1\ 296\right)$ MW flows on the Tutuka-Alpha lines. The generation at Koeberg is $P_{KBG} = 450$ MW. Therefore:

$$P_{SP} = 1\ 320 + 1\ 296 = 2\ 616 \text{ MW.} \tag{E.4-a}$$

$$P_{KBG} = 450 \text{ MW.} \tag{E.4-b}$$

Substituting P_{SP} and P_{KBG} into equation E.3 gives:

$$P_{PP} = 26\ 118 - \left(2\ 616 + 450\right) \text{ MW.}$$

$$= 23\ 052 \text{ MW.} \tag{E.5}$$

This dissertation assumes all the Mpumalanga generators have a rated turbine power output of 675 MW and 750 MVA. When subtracting the auxiliary plant, i.e. 30 MW, the generator output as seen by the network is obtained. Therefore, the generator output is 645 MW.

The number of on-line generators, n_{PP}, in the Primary Pool is $n_{PP} = 23\ 052/645 \approx 36$. Therefore, the base MVA, S_{PP}^{BASE}, of the Primary Pool is:

$$S_{PP}^{BASE} = 36 \times 750 \text{ MVA}$$
$$= 27\ 000 \text{ MVA} \quad \text{(E.6)}$$

The power, P_{SP}, generated in the Secondary Pool is $P_{SP} = 2\ 616$ MW (equation E.4-a). Therefore, the number of on-line generators, n_{SP}, in the Secondary Pool is $n_{SP} = 2\ 616/645 \approx 4$. Hence, the base MVA, S_{SP}^{BASE}, of the Secondary Pool is:

$$S_{SP}^{BASE} = 4 \times 750 \text{ MVA}$$
$$= 3\ 000 \text{ MVA} \quad \text{(E.7)}$$

E.2.1.2 Computing x'_{PP} and X_{PP}^{TRFR}

The base MVA, S_{PP}^{BASE}, of the Primary pool is $27\ 000$ MVA (equation E.6). Consequently, the parameters of the 750 MVA generator must be changed to represent a $27\ 000$ MVA generator.

With regard to changing the parameters of a typical 750 MVA generator to realise the $27\ 000$ MVA generator, we note the per unit reactance of the 750 MVA generator is the per unit reactance of the $27\ 000$ MVA generator.

The first step in explaining the above statement is to determine how many 750 MVA generators need to operate in parallel to achieve a $27\ 000$ MVA generation pool. Assume the number is A, then:

$$A = \frac{27\ 000}{750}\ \frac{MVA}{MVA} \qquad \text{(E.8-a)}$$

Assume the per unit impedance of the 750 MVA generator is $\boldsymbol{Z}$. The equivalent impedance, $\boldsymbol{Z}_{PP}$, of A times 750 MVA generators operating in parallel is:

$$\frac{1}{\boldsymbol{Z}_{PP}} = \frac{1}{\boldsymbol{Z}}\ A$$

$$\boldsymbol{Z}_{PP} = \boldsymbol{Z}\ \frac{1}{A}$$

$$= \boldsymbol{Z}\ \frac{750}{27\ 000}\ \text{p.u;}\ S_{BASE} = 750\ \text{MVA.} \qquad \text{(E.8-b)}$$

PSS/E expresses the generator's parameters on the generator base MVA. To convert the base MVA of $\boldsymbol{Z}_{PP}$ from 750 MVA to $27\ 000$ MVA we need to multiply $\boldsymbol{Z}_{pp}$ with $B = 27\ 000/750$ (Chapter 3, equation 3.31-c). We have:

$$\boldsymbol{Z}_{PP} = \boldsymbol{Z}\ \frac{1}{A}B$$

$$= \boldsymbol{Z}\ \frac{750}{27\ 000} \times \frac{27\ 000}{750}$$

$$= \boldsymbol{Z}\ \text{p.u;}\ S_{BASE} = 27\ 000\ \text{MVA.} \qquad \text{(E.8-c)}$$

To allow comparing the Primary pool impedances with the transmission network impedances the Primary pool impedances are converted to a 100 MVA base.

The transient reactance of a typical 750 MVA generator is 0.336 p.u; $S_{BASE} = 750$ MVA. Therefore, the transient reactance, x'_{PP}, of the Primary Pool generator, expressed on a 100 MVA base, is:

$$x'_{PP} = 0.336 \times \frac{100}{27\ 000}$$

$$= 0.00124 \text{ p.u; } S_{BASE} = 100 \text{ MVA.} \quad \text{(E.9)}$$

The reactance of a typical 750 MVA generator transformer is 0.125 p.u; $S_{BASE} = 750$ MVA . Therefore, the reactance, X_{PP}^{TRFR}, of the Primary Pool generator transformer, expressed on a 100 MVA base, is:

$$X_{PP}^{TRFR} = 0.125 \times \frac{100}{27\ 000}$$

$$= 0.00046 \text{ p.u; } S_{BASE} = 100 \text{ MVA.} \quad \text{(E.10)}$$

E.2.1.3 Computing x'_{SP} and X_{SP}^{TRFR}

The base MVA, S_{SP}^{BASE}, of the Secondary pool is 3 000 MVA (equation E.7). Hence, the parameters of the 750 MVA generator must be changed to represent a 3 000 MVA generator.

With regard to changing the parameters of a typical 750 MVA generator to realise the 3 000 MVA generator, we note the per unit reactance of the 750 MVA generator is the per unit reactance of the 3 000 MVA generator.

To allow comparing the Primary pool impedances with the transmission network impedances the Primary pool impedances are converted to a 100 MVA base.

The transient reactance of a typical 750 MVA generator is 0.336 p.u; $S_{BASE} = 750$ MVA. Therefore, the transient reactance, x'_{SP}, of the Secondary Pool generator, expressed on a 100 MVA base, is:

$$x'_{SP} = 0.336 \times \frac{100}{3\ 000}$$

$$= 0.01120 \text{ p.u; } S_{BASE} = 100 \text{ MVA.} \quad \text{(E.11)}$$

The reactance of a typical 750 MVA generator transformer is 0.125 p.u; $S_{BASE} = 750$ MVA. Therefore, the reactance, X_{SP}^{TRFR}, of the Secondary Pool generator transformer, expressed on a 100 MVA base, is:

$$X_{SP}^{TRFR} = 0.125 \times \frac{100}{3\ 000}$$

$$= 0.00417 \text{ p.u; } S_{BASE} = 100 \text{ MVA.} \quad \text{(E.12)}$$

E.2.2 Computing X_{LINK}

To compute X_{LINK} the through put power, P_{LINK}, at $\boldsymbol{V}_{\boldsymbol{PP}}^{\boldsymbol{HV}}$ the Mpumalanga generator exports to Perseus/Beta must be known.

To compute P_{LINK}, the Atlas infeed of 162 MW (Chapter 3, figure 3.8) is subtracted from P_{GA}. P_{LINK} is (equation E.1-a):

$$P_{LINK} = 2\ 921 - 162 \text{ MW.}$$

$$= 2\ 759 \text{ MW.} \quad \text{(E.13)}$$

No active power losses occur between the busbars $\boldsymbol{V}_{\boldsymbol{PP}}^{\boldsymbol{HV}}$ and $\boldsymbol{V}_{\boldsymbol{MPU}}$. Hence, X_{LINK} can be computed using:

$$X_{LINK} = \frac{\sin(\delta_{PP \to MPU})}{P_{LINK}} \times \left|\boldsymbol{V}_{\boldsymbol{PP}}^{\boldsymbol{HV}}\right| \left|\boldsymbol{V}_{\boldsymbol{MPU}}\right| \quad \text{(E.14)}$$

Where V_{PP}^{HV} is the high voltage busbar of the Primary Pool generator; V_{MPU} is the Grootvlei/Atlas/Tutuka busbar and $\delta_{PP \rightarrow MPU}$ is the power angle with which V_{PP}^{HV} leads V_{MPU}.

$\delta_{PP \rightarrow MPU}$ can be computed using:

$$\delta_{PP \rightarrow MPU} = \delta_{PP}^{HV} - \delta_{MPU} \tag{E.15}$$

Where δ_{PP}^{HV} is the power angle for V_{PP}^{HV}; and δ_{MPU} is the power angle of V_{MPU}.

To clarify the computation of δ_{PP}^{HV}, we note Matla is the northern border and Arnot the southern border of the Primary Pool. Hence, δ_{PP}^{HV} can be computed using:

$$\delta_{PP}^{HV} = \frac{\delta_{MATLA4} + \delta_{ARNOT4}}{2} \tag{E.16}$$

The values δ_{MATLA4} and δ_{ARNOT4} obtain in the simplified network model are $\delta_{MATLA4} = -1.86^{\circ}$ and $\delta_{ARNOT4} = -2.13^{\circ}$. Hence:

$$\delta_{PP}^{HV} = \frac{-1.86^{\circ} - 2.13^{\circ}}{2}$$

$$\approx -2.0^{\circ} \tag{E.17}$$

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

$$\delta_{MPU} = \left(\frac{\delta_{GRTVL4} + \delta_{ATLAS4} + \delta_{TUTUK4}}{3} \right) \tag{E.18}$$

The values δ_{GRTVL4}, δ_{ATLAS4} and δ_{TUTUK4} obtain in the simplified network model are $\delta_{GRTVL4} = -14.4^\circ$, $\delta_{ATLAS4} = -15.2^\circ$ and $\delta_{TUTUK4} = -11.6^\circ$. Hence:

$$\delta_{MPU} = \frac{\left(-14.4^\circ - 15.2^\circ - 11.6^\circ\right)}{3}$$

$$= -13.73^\circ \qquad \text{(E.19)}$$

Therefore, $\delta_{PP \to MPU}$ is:

$$\delta_{PP \to MPU} = \delta_{PP}^{HV} - \delta_{MPU}$$

$$= -2^\circ + 13.73^\circ$$

$$= 11.73^\circ \qquad \text{(E.20)}$$

The magnitude $\left|V_{MPU}\right|$ obtains in the simplified network model is $\left|V_{MPU}\right| = 1.001$ p.u. (Chapter 3, equation 3.20-a) and the magnitude $\left|V_{PP}^{HV}\right|$ obtains in the simplified network model is $\left|V_{PP}^{HV}\right| = 1.0235$ (equation E.2-b).

When substituting $\left|V_{PP}^{HV}\right| = 1.0235$ p.u, $\left|V_{MPU}\right| = 1.001$ p.u, $\delta_{PP \to MPU} = 11.73^\circ$ and $P_{LINK} = 27.59$ p.u ($S_{BASE} = 100$ MVA) into equation E.14 we obtain:

$$X_{LINK} = \frac{\sin\left(\delta_{PP \to MPU}\right)}{P_{LINK}} \times \left|V_{PP}^{HV}\right| \left|V_{MPU}\right|$$

$$= \frac{\sin\left(11.73^\circ\right)}{27.59} \times 1.0235 \times 1.001 \text{ p.u.}$$

$$= 0.00755 \text{ p.u; } S_{BASE} = 100 \text{ MVA} \qquad \text{(E.21)}$$

E.2.3 Computing Q_{PP-L}

When connecting the Western Cape generation pool (Chapter 3, figure 3.19), the Primary generation pool (figure E.1) and the Secondary generation pool (figure E.2) to the tie line model (Chapter 3, figure 3.14), the load flow shown in figure E.3 is obtained.

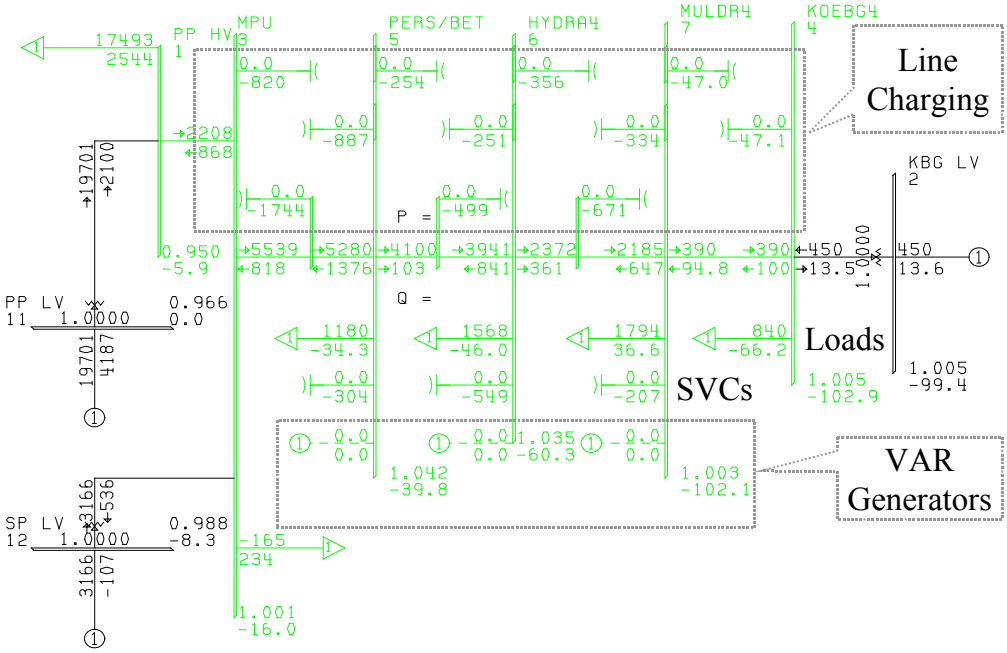


FIGURE E.3 Load flow of the three generator model of the Mpumalanga-to-Western-Cape network

Figure E.3 shows when Q_{PP-L} is set equal to $2\ 544.0$ MVAR when $|V_{MPU}| = 1.001$ p.u. the Primary Pool generator operates at a 0.98 power factor.

Q_{PP-L} expressed as a demand at per unit voltage is:

$$Q_{PP-L} = 2\ 819.0 \text{ MVAR}. \tag{E.22}$$