APPENDIX 4

EXAMPLE 4 - DETERMINATION OF Z-RATIO BY PLANT PERFORMANCE TEST

A test was carried out in which the two pass-out streams from the steam turbine in a Scheme were altered in turn whilst endeavouring to maintaining a constant steam flow to the ST.

The flow of LP steam to the deaerator and condensate heater was estimated at 4.0 te/h. This was assumed to remain unchanged.

Since there are two pass-out streams and a condenser (vacuum exhaust) steam, we need to derive the specific electricity generation (kW per tonne/h of steam, i.e. kWh/tonne) for each stream.

To solve for three unknowns three independent sets of data are required. The three sets of test data are:

	Total steam te/h	LP steam to site, te/h	MP steam to site, te/h	Generation kWe
1. Initial operation	82.9	28.0	25.5	9,471
2. Increased MP pass-out	84.0	28.0	30.0	10,056
3. Increased LP pass-out	83.5	33.0	25.0	10,255

Step 1: Derive LP pass-out (= LP steam to site + 4.0 te/h) and flow of steam to condenser

	Total steam te/h	LP pass-out te/h	MP pass-out te/h	Condenser steam te/h	Generation kWe
Case 1	82.9	32.0	25.5	25.4	10,626
Case 2	84.0	32.0	30.0	22.0	10,056
Case 3	83.5	37.0	25.0	21.5	10,255

Step 2: Normalise data to a total steam flow of 84.0 te/h

	Total steam te/h	LP pass-out te/h	MP pass-out te/h	Condenser steam te/h	Generation kWe
Case 1	84.0	32.425	25.838	25.737	10,767
Case 2	84.0	32.000	30.000	22.000	10,056
Case 3	84.0	37.221	25.150	21.629	10,317

Step 3: Calculate the kWh/tonne of steam to MP pass-out, LP pass-out and condenser by solving 3 simultaneous equations

Solution of simultaneous linear equations

Form: $W = aX + bY + cZ$

Equation 1 $10{,}767 = 32.425\ a + 25.838\ b + 25.737\ c$

Equation 2 $10{,}317 = 37.221\ a + 25.150\ b + 21.629\ c$

Equation 3	10,056	=	32.000	a	+ 30.000	b	+	22.000	c
Eliminate a	8,987.6	=	32.425	a	+ 21.909	b	+	18.842	c
	10,189.6	=	32.425	a	+ 30.398	b	+	22.292	c
Equation A	1779.4	=	3.929	b	+ 6.895	c			
Equation B	577.4	=	-4.560	b	+ 3.445	c			
Eliminate b	-497.4	=	3.929	b	+ -2.968	c			
	-2276.8	=	0.000	b	+ -9.863	c			
	c	=	230.86						
Substitute in Equation A	b	=	47.76						
Solve Equation 1 for a	a	=	110.76						
Check in Equation 2	10,317	=	4,122.7	+	1,201.2	+	4,993.1	OK	
Check in Equation 3	10,056	=	3,544.4	+	1,432.8	+	5,078.8	OK	

Step 4: Heat to site per tonne/h of MP and LP pass-out

MP pass-out condition: 15 bar / 295°C, specific enthalpy 3,027 kJ/kg (datum 0°C) Site datum 10°C, water specific enthalpy 42 kJ/kg

Heat to site in MP pass-out = (3,027 – 42) kJ/kg = 2,985 kJ/kg = 2,985 MJ/tonne

$$= 2{,}985 \frac{MJ}{tonne} \times \frac{1}{3.6} \frac{kWh}{MJ}$$

= 829 kWh/tonne

LP pass-out condition: 4 bar / 165°C, specific enthalpy 2,786 kJ/kg (datum 0°C) Site datum 10°C, water specific enthalpy 42 kJ/kg

Heat to site in MP pass-out = (2,786 – 42) kJ/kg = 2,744 kJ/kg = 2,744 MJ/tonne

$$= 2{,}744 \frac{MJ}{tonne} \times \frac{1}{3.6} \frac{kWh}{MJ}$$

= 762 kWh/tonne

Step 5: Determine Z factor for MP and LP pass-out for 1 tonne/h increased MP pass-out

$$Increased\ heat\ to\ site = 829\ kWhth$$

$$Reduction\ in\ generation = 230.86\ kWhe - 47.76\ kWhe = 183.10\ kWhe$$

$$Z - factor = \frac{829\ kWhth}{183.1\ kWhe} = 4.54$$

For 1 tonne/h increased LP pass-out

$$Increased\ heat\ to\ site = 762\ kWhth$$

$$Reduction\ in\ generation = 230.86\ kWhe - 110.76\ kWhe = 120.10\ kWhe$$

$$Z - factor = \frac{762\ kWhth}{120.10.1\ kWhe} = 6.34$$

Step 6: Determine weighted mean Z-factor

Annual average MP steam to site = 28.7 tonnes/h

Annual average LP steam pass-out = (30.3 + 4) = 34.3 tonnes/h

Annual average total pass-out = (28.7+34.3) = 63.0 tonnes/h

$$Weighted\ mean\ Z - factor = \frac{\left[\left(28.7\ \frac{tonnes}{h}\right) \times 4.53\right] + \left[\left(34.3\ \frac{tonnes}{h}\right) \times 6.34\right]}{63\,\frac{tonnes}{h}}$$

$$= \mathbf{5.52}$$

