

Risk-Constrained Generating Asset Arbitrage

Table I Market price

| Hour | Energy Price (\$/MWh) | Variance of energy price | Spinning reserve (\$/MW) | Variance of spinning reserve price | Variance of non-spinning reserve price | Non-spinning reserve (\$/MW) |
|------|-----------------------|--------------------------|--------------------------|------------------------------------|--|------------------------------|
| 1 | 21.71 | 10.86 | 2 | 0.3 | 1.2 | 0.18 |
| 2 | 17.5 | 8.75 | 1.7 | 0.26 | 0.9 | 0.14 |
| 3 | 13.05 | 6.53 | 1.27 | 0.19 | 0.47 | 0.07 |
| 4 | 12.15 | 6.08 | 1.12 | 0.17 | 0.32 | 0.05 |
| 5 | 13.77 | 6.89 | 1.35 | 0.2 | 0.55 | 0.08 |
| 6 | 15.99 | 8 | 2.18 | 0.33 | 1.38 | 0.21 |
| 7 | 20.99 | 10.5 | 2.17 | 0.33 | 1.37 | 0.21 |
| 8 | 23.01 | 11.51 | 2.34 | 0.35 | 1.54 | 0.23 |
| 9 | 23.85 | 11.93 | 2.51 | 0.38 | 1.71 | 0.26 |
| 10 | 26.11 | 13.05 | 2.69 | 0.4 | 1.89 | 0.28 |
| 11 | 27.23 | 13.62 | 2.94 | 0.44 | 2.14 | 0.32 |
| 12 | 27.99 | 14 | 2.95 | 0.44 | 2.15 | 0.32 |
| 13 | 28.7 | 14.35 | 2.77 | 0.42 | 1.97 | 0.3 |
| 14 | 27.9 | 13.95 | 2.87 | 0.43 | 2.07 | 0.31 |
| 15 | 27.55 | 13.77 | 2.92 | 0.44 | 2.12 | 0.32 |
| 16 | 27.73 | 13.86 | 3.32 | 0.5 | 2.52 | 0.38 |
| 17 | 28.13 | 14.06 | 3.23 | 0.48 | 2.43 | 0.36 |
| 18 | 28.56 | 14.28 | 2.97 | 0.45 | 2.17 | 0.33 |
| 19 | 28.8 | 14.4 | 2.96 | 0.44 | 2.16 | 0.32 |
| 20 | 30.83 | 15.41 | 2.73 | 0.41 | 1.93 | 0.29 |
| 21 | 30.81 | 15.4 | 2.35 | 0.35 | 1.55 | 0.23 |
| 22 | 29.34 | 14.67 | 1.76 | 0.26 | 0.96 | 0.14 |
| 23 | 26.56 | 13.28 | 1.57 | 0.24 | 0.77 | 0.12 |
| 24 | 21.15 | 10.58 | 1.16 | 0.17 | 0.36 | 0.05 |

Table II Market Fuel Price

| Fuel | Fuel Price (\$/MBtu) | Fuel Price Variance |
|------|----------------------|---------------------|
| Coal | 1.2 | 0.1 |
| Gas | 1.8 | 0.1 |

Table III Fossil Unit Data

| Unit | Bus No | Pmin (MW) | Pmax (MW) | Qmin (MW) | Qmax (MW) | Min ON (Hour) | Min OFF (Hour) | Ramp Up (MW/Hour) | Ramp Down (MW/Hour) | qsc (MW) | MSR (MW/min) | IniT (Hour) | St Mbtu | Fuel Type | Fuel Price (\$/Mbtu) | Ems Coef (lbs/Mbtu) | af (Mbtu/MW ² h) | bf (Mbtu/MWh) | cf (Mbtu/h) |
|------|--------|-----------|-----------|-----------|-----------|---------------|----------------|-------------------|---------------------|----------|--------------|-------------|---------|-----------|----------------------|---------------------|-----------------------------|---------------|-------------|
| 1011 | 26 | 100 | 350 | -1000 | 1000 | 8 | 8 | 175 | 175 | 0 | 3.5 | 8 | 100 | Coal | 1 | 0.35 | 0.00300 | 10.7600 | 32.96 |
| 1012 | 27 | 8 | 30 | -300 | 300 | 1 | 1 | 15 | 15 | 30 | 1 | 1 | 40 | Gas | 1.5 | 0 | 0.06966 | 26.2438 | 31.67 |
| 1013 | 31 | 8 | 30 | -300 | 300 | 1 | 1 | 15 | 15 | 30 | 1 | 1 | 40 | Gas | 1.5 | 0 | 0.06966 | 26.2438 | 31.67 |
| 1014 | 32 | 25 | 100 | -14 | 42 | 5 | 5 | 50 | 50 | 0 | 1 | 5 | 50 | Coal | 1 | 0 | 0.01280 | 17.8200 | 10.15 |
| 1015 | 34 | 8 | 30 | -8 | 24 | 1 | 1 | 15 | 15 | 30 | 1 | 1 | 40 | Gas | 1.5 | 0.3 | 0.06966 | 26.2438 | 31.67 |
| 1016 | 36 | 25 | 100 | -8 | 24 | 5 | 5 | 50 | 50 | 0 | 1 | 5 | 50 | Coal | 1 | 0.3 | 0.01280 | 17.8200 | 10.15 |
| 1017 | 40 | 8 | 30 | -300 | 300 | 1 | 1 | 15 | 15 | 30 | 1 | 1 | 40 | Gas | 1.5 | 0.3 | 0.06966 | 26.2438 | 31.67 |
| 1018 | 42 | 8 | 30 | -300 | 300 | 1 | 1 | 15 | 15 | 30 | 1 | 1 | 40 | Gas | 1.5 | 0.3 | 0.06966 | 26.2438 | 31.67 |
| 1019 | 46 | 25 | 100 | -100 | 100 | 5 | 5 | 50 | 50 | 0 | 1 | 5 | 59 | Coal | 1 | 0 | 0.01280 | 17.8200 | 10.15 |
| 1020 | 49 | 50 | 250 | -85 | 210 | 8 | 8 | 125 | 125 | 0 | 2.5 | 8 | 100 | Coal | 1 | 0 | 0.00240 | 12.3299 | 28.00 |
| 1021 | 54 | 50 | 250 | -300 | 300 | 8 | 8 | 125 | 125 | 0 | 1 | 8 | 100 | Coal | 1 | 0.25 | 0.00240 | 12.3299 | 28.00 |
| 1022 | 55 | 25 | 100 | -8 | 23 | 5 | 5 | 50 | 50 | 0 | 1 | 5 | 50 | Coal | 1 | 0.25 | 0.01280 | 17.8200 | 10.15 |
| 1023 | 56 | 25 | 100 | -8 | 15 | 5 | 5 | 50 | 50 | 0 | 1 | 5 | 50 | Coal | 1 | 0.25 | 0.01280 | 17.8200 | 10.15 |
| 1024 | 59 | 50 | 200 | -60 | 180 | 8 | 8 | 100 | 100 | 0 | 2 | 10 | 100 | Coal | 1 | 0.25 | 0.00440 | 13.2900 | 39.00 |
| 1025 | 61 | 50 | 200 | -100 | 300 | 8 | 8 | 100 | 100 | 0 | 2 | 10 | 100 | Coal | 1 | 0 | 0.00440 | 13.2900 | 39.00 |
| 1026 | 62 | 25 | 100 | -20 | 20 | 5 | 5 | 50 | 50 | 0 | 1 | 5 | 50 | Coal | 1 | 0 | 0.01280 | 17.8200 | 10.15 |
| 1027 | 65 | 100 | 420 | -67 | 200 | 10 | 10 | 210 | 210 | 0 | 4.2 | 10 | 250 | Coal | 1 | 0 | 0.01059 | 8.3391 | 64.16 |
| 1028 | 66 | 100 | 420 | -67 | 200 | 10 | 10 | 210 | 210 | 0 | 4.2 | 10 | 250 | Coal | 1 | 0.2 | 0.01059 | 8.3391 | 64.16 |
| 1029 | 69 | 80 | 300 | -9999 | 9999 | 8 | 8 | 150 | 150 | 0 | 3 | 10 | 100 | Coal | 1 | 0.2 | 0.01088 | 12.8875 | 6.78 |
| 1030 | 70 | 30 | 80 | -10 | 32 | 4 | 4 | 40 | 40 | 0 | 1 | 4 | 45 | Coal | 1 | 0.2 | 0.04592 | 15.4708 | 74.33 |

Table IV Combined Cycle Unit Data

| Unit | Bus No | Total # of CT | Total # of ST | Total # Config | qsc (MW) | MSR (MW/min) | CT St Mbtu | ST St Mbtu | Ems Coef (lbs/Mbtu) | Init Config | IniT (Hour) |
|------|--------|---------------|---------------|----------------|----------|--------------|------------|------------|---------------------|-------------|-------------|
| 4001 | 12 | 2 | 1 | 5 | 50 | 4 | 30 | 15 | 0.1 | 0 | 3 |
| 4002 | 61 | 2 | 1 | 5 | 50 | 4 | 120 | 60 | 0.1 | 0 | 3 |
| 4003 | 62 | 2 | 1 | 5 | 50 | 4 | 320 | 160 | 0.1 | 0 | 3 |
| 4004 | 66 | 2 | 1 | 5 | 70 | 5 | 40 | 20 | 0.1 | 0 | 3 |

Table V Combined Cycle Unit Configuration Data

| Unit | Config # | CT | ST | Pmin (MW) | Pmax (MW) | Qmin (MW) | Qmax (MW) | Tmin (Hour) | Ramp Up (MW/Hour) | Ramp Down (MW/Hour) | af (Mbtu/MW ² h) | bf (Mbtu/MWh) | cf (Mbtu/h) |
|------|----------|----|----|-----------|-----------|-----------|-----------|-------------|-------------------|---------------------|-----------------------------|---------------|-------------|
| 4001 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 3 | 0.0 | 0.0 | 0.02533 | 16.5420 | 34.3891 |
| 4001 | 1 | 1 | 0 | 5.0 | 25.0 | -4.0 | 20.0 | 2 | 25.0 | 25.0 | 0.02533 | 16.5420 | 34.3891 |
| 4001 | 2 | 2 | 0 | 10.0 | 50.0 | -8.0 | 40.0 | 2 | 50.0 | 50.0 | 0.01266 | 16.5420 | 68.7782 |
| 4001 | 3 | 1 | 1 | 7.5 | 37.5 | -6.0 | 30.0 | 2 | 37.5 | 37.5 | 0.01359 | 14.3272 | 61.2980 |
| 4001 | 4 | 2 | 1 | 15.0 | 75.0 | -12.0 | 60.0 | 2 | 75.0 | 75.0 | 0.00962 | 13.5073 | 134.1259 |
| 4002 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 3 | 0.0 | 0.0 | 0.01059 | 13.1083 | 70.0288 |
| 4002 | 1 | 1 | 0 | 5.0 | 25.0 | -4.0 | 20.0 | 2 | 25.0 | 25.0 | 0.01059 | 13.1083 | 70.0288 |
| 4002 | 2 | 2 | 0 | 10.0 | 50.0 | -8.0 | 40.0 | 2 | 50.0 | 50.0 | 0.00530 | 13.1083 | 140.0576 |
| 4002 | 3 | 1 | 1 | 7.5 | 37.5 | -6.0 | 30.0 | 2 | 37.5 | 37.5 | 0.00876 | 10.8416 | 112.3179 |
| 4002 | 4 | 2 | 1 | 15.0 | 75.0 | -12.0 | 60.0 | 2 | 75.0 | 75.0 | 0.00267 | 9.3016 | 189.6272 |
| 4003 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 3 | 0.0 | 0.0 | 0.00505 | 10.6121 | 130.0021 |
| 4003 | 1 | 1 | 0 | 5.0 | 25.0 | -4.0 | 20.0 | 2 | 25.0 | 25.0 | 0.00505 | 10.6121 | 130.0021 |
| 4003 | 2 | 2 | 0 | 10.0 | 50.0 | -8.0 | 40.0 | 2 | 50.0 | 50.0 | 0.00253 | 10.6121 | 260.0042 |
| 4003 | 3 | 1 | 1 | 7.5 | 37.5 | -6.0 | 30.0 | 2 | 37.5 | 37.5 | 0.00278 | 9.8416 | 190.1760 |
| 4003 | 4 | 2 | 1 | 15.0 | 75.0 | -12.0 | 60.0 | 2 | 75.0 | 75.0 | 0.00143 | 7.5121 | 406.9102 |
| 4004 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 3 | 0.0 | 0.0 | 0.01736 | 14.4921 | 58.1310 |
| 4004 | 1 | 1 | 0 | 8.0 | 35.0 | -6.4 | 28.0 | 2 | 35.0 | 35.0 | 0.01736 | 14.4921 | 58.1310 |
| 4004 | 2 | 2 | 0 | 16.0 | 70.0 | -12.8 | 56.0 | 2 | 70.0 | 70.0 | 0.00866 | 14.4921 | 116.2620 |
| 4004 | 3 | 1 | 1 | 12.0 | 50.0 | -9.6 | 40.0 | 2 | 50.0 | 50.0 | 0.01328 | 12.5752 | 72.6481 |
| 4004 | 4 | 2 | 1 | 25.0 | 100.0 | -20.0 | 80.0 | 2 | 100.0 | 100.0 | 0.00588 | 11.0800 | 129.7552 |