Appendix

Data of PGE hybrid power system

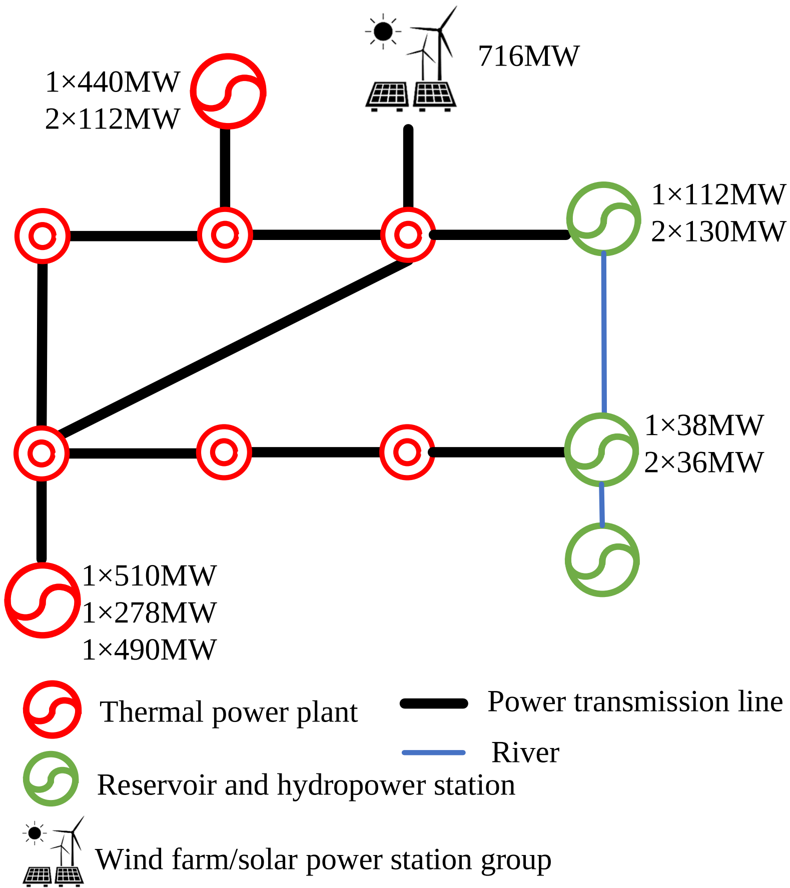


Figure 1: Schematic diagram of PGE power system

In water-to-power conversion constraints, we divide reservoir volume interval $\left[V_{h_p}^{\min}, V_{h_p}^{\max}\right]$ into three sub-intervals with equal range, corresponding to "low volume", "normal volume" and "high volume". The third column of the following table gives the water-to-power conversion functions under normal volume. The generation efficiency will increase by 5% under high volume and decrease by 8% under low volume.

The following table gives the parameters of thermal power units:

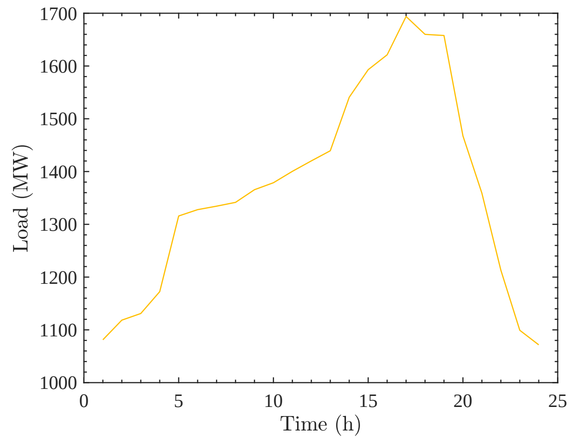


Figure 2: The electricity load of the hybrid power system

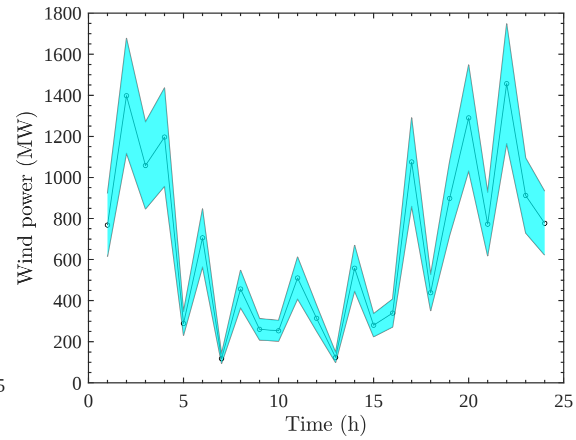
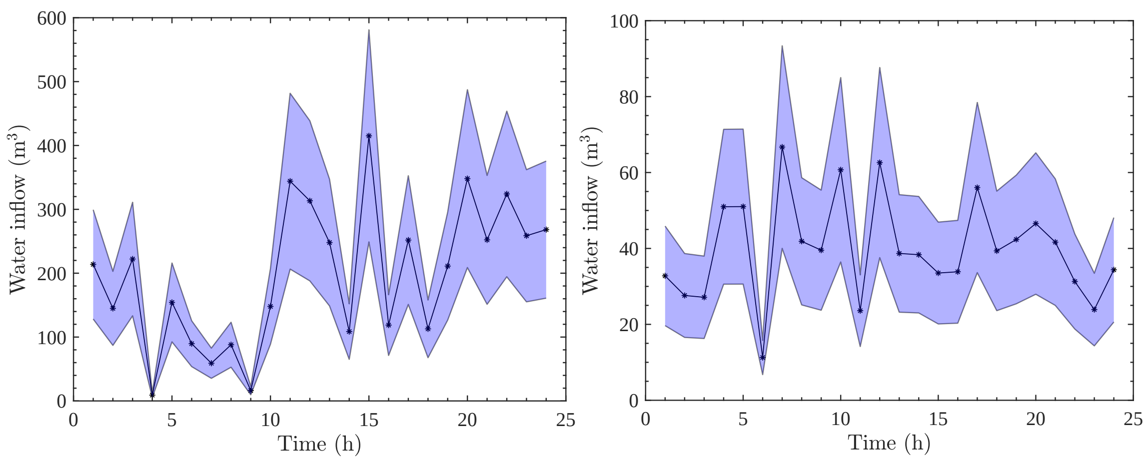


Figure 3: The uncertainty set of wind power



(a) Round Butte

(b) Pelton

Figure 4: The uncertainty set of natural water inflow

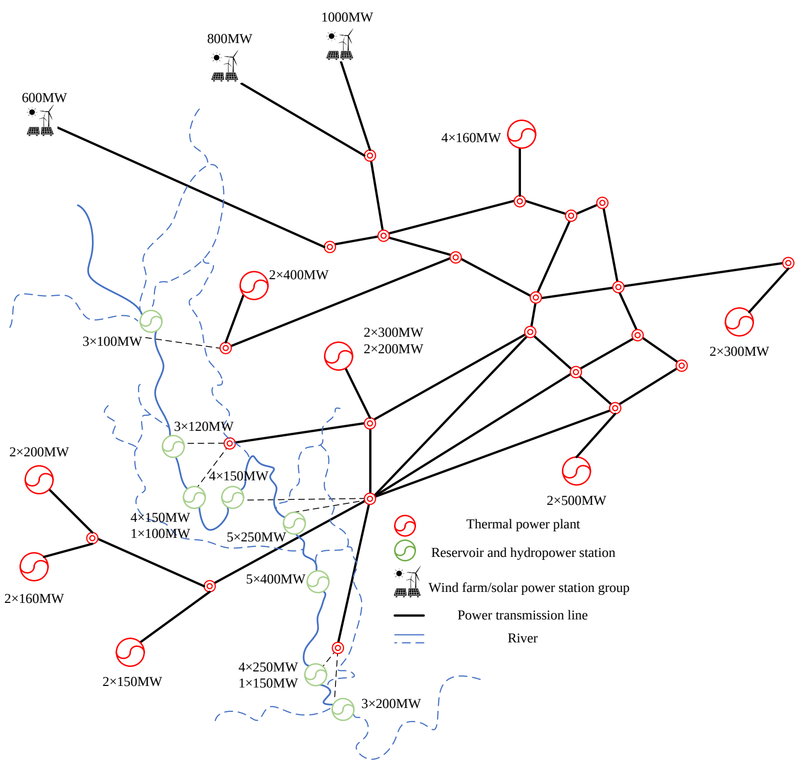


Figure 5: Schematic diagram of the provincial power system in southwest China

Table 1: The parameters of the reservoirs

Reservoir	$V_{h_p}^{ini}$ (10^3 m^3)	$V_{h_p}^{\min}/V_{h_p}^{\max}$ (10^3 m^3)	Water time delay (h)
Round Butte	130,670	130,667/130,672	–
Pelton	1,160	1,158/1,163	1
Rereg	1,552	1,550/1,554	1

Table 2: The parameters of hydroelectric units

Units	$p_h^{\min}/p_h^{\max}$ (MW)	Water-to-power function (m^3, MWh)	Location
1	1/112	-4.55E-05x^3+7.62E-03$x^2+0.76x-7.25$	Round Butte
2	1/130	-4.10E-05x^3+7.62E-03$x^2+0.71x-95.98$	Round Butte
3	1/130	-4.55E-05x^3+1.02E-02$x^2+0.54x+15.98$	Round Butte
4	12/38	-9.11E-05x^3+1.27E-02$x^2-0.34x+374.56$	Pelton
5	12/36	-9.11E-05x^3+1.27E-02$x^2-0.34x+374.56$	Pelton
6	12/36	-9.11E-05x^3+1.27E-02$x^2-0.34x+374.56$	Pelton

Table 3: The parameters of thermal power units

Units	Min/Max power output (MWh)	Min on/off time (h)	Max ramping rate (MW/h)	Cost ($/MWh)
1	6/112	1/1	70	30
2	6/112	1/1	70	30
3	140/278	48/3	195	20
4	1/440	1/1	290	20
5	1/490	1/1	360	20
6	5/510	2/1	365	20

Data of a provincial hybrid power system in southwest China

We assume that each uncertain parameter fluctuates over the range between 80% and 120% of its nominal value.

The hydroelectric units with the same installed capacity share the same water-to-power conversion function.

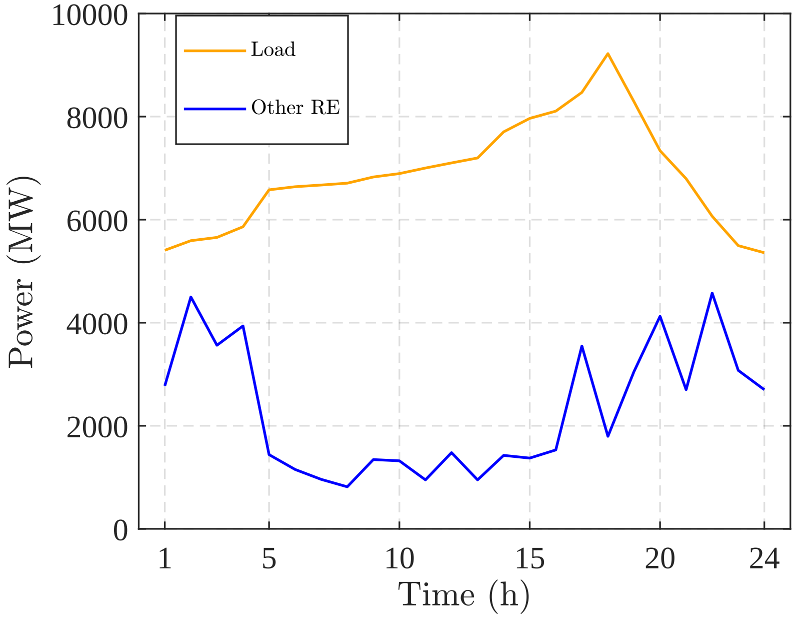


Figure 6: Electricity load and other renewable energy output except hydroelectric generation

Table 4: The parameters of reservoirs

Reservoir	$V_{h_p}^{ini}$ (10^6 m^3)	$V_{h_p}^{\min}/V_{h_p}^{\max}$ (10^6 m^3)	$QS_{h_p}^{\min}/QS_{h_p}^{\max}$ (m^3/s)	Water time delay (h)
#1	2.86	2.01/4.23	724.9	–
#2	3.43	2.56/4.97	790.3	3/5/7
#3	8.01	5.58/8.93	1853.1	1/2/3
#4	5.78	3.41/6.36	1807.9	1/2/3
#5	13.24	10.60/17.24	3181.2	2/3/4
#6	20.99	11.09/34.12	4608.4	1/2/3
#7	17.21	8.77/20.53	5276.1	2/3/4
#8	12.32	9.05/15.46	5994.5	1/2/3

Table 5: The nominal values of natural water inflow (m^3/s)

Time \ Reservoir	#1	#2	#3	#4	#5	#6	#7	#8
1	53.49	10.79	30.73	32.96	59.12	116	112.84	117.76
2	32.77	6.92	22.56	19.1	45.86	85.97	86.54	83
3	66.99	14.89	43.89	50.13	106.61	220.12	237.52	211.69
4	168.93	34.3	82.54	124.05	171.72	372.16	311.12	366.58
5	476.73	69.44	177.67	273	334.12	664.16	415.61	590.82
6	642.35	86.65	187.25	270.72	396.24	718.64	388.85	639.88
7	478.48	73.1	127.37	192.17	265.82	486.45	271.14	440.16
8	355.19	56.09	96.31	119.68	202.58	314.01	187.14	325.81
9	241.02	39.19	75.12	90.29	145.13	285.92	185	234.92
10	125.65	23.17	49.14	58.23	103.77	209.05	159.61	184.18
11	52.57	10.63	28.07	29.2	54.11	100.26	84.28	99.29
12	36.43	7.17	20.01	20.42	37.43	73.44	64.19	74.03
13	33.64	6.8	19.13	20.55	37.08	72.65	70.64	73.33
14	32.43	6.9	22.27	18.92	45.39	85	85.93	82.39
15	43.29	9.63	28.32	32.45	69.11	142.34	153.59	136.76
16	200.83	40.72	98.29	147.5	204.28	444.49	369.52	436.46
17	559.62	81.48	208.7	319.17	393.65	780.91	489.4	697.93
18	842.94	113.49	245.38	355.53	518.95	940.43	510.35	837.21
19	552.52	84.79	147.48	222.7	309.09	563.47	311.82	509.22
20	413.26	64.9	111.48	138.53	234.67	362.93	216.67	377.27
21	206.02	33.73	64.56	77.28	124.21	245.15	158.42	201.21
22	116.03	21.43	45.4	53.95	96.08	193.31	147.49	170.19
23	49.54	9.73	27.2	27.9	51.03	100.08	87.47	100.48
24	45.72	9.16	24.27	25.47	46.84	86.94	73.12	86.46

Table 6: The parameters of hydroelectric units

# of units	$p_h^{\min}/p_h^{\max}$ (MW)	Water-to-power function (m^3, MWh)
4	1/100	-4.61E-05x^3 7.31E-03x^2 0.75E-01x -7.25
3	1/120	-5.61E-05x^3 9.14E-03x^2 0.68E-01x -6.25
9	1/150	-7.79E-05x^3 1.49E-02x^2 0.23x 4.05
3	1/200	-1.51E-05x^3 -2.23E-04x^2 1.32x -18.1
9	1/250	-4.48E-05x^3 6.61E-03x^2 0.96x -8.85
5	1/400	-2.12E-05x^3 1.30E-03x^2 1.20x -1.63

Table 7: The parameters of thermal power units

# of units	Min/Max power output (MWh)	Min on/off time (h)	Max ramping rate (MW/h)	Cost ($/MWh)
2	10/150	1/1	80	25
6	10/160	1/1	90	25
4	30/200	2/1	120	24
4	40/300	2/2	140	22
2	45/400	2/2	200	20
2	60/500	2/2	240	20