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A Real Test System For Power System Planning, Operation, and Reliability

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Abstract
Nowadays, several test systems available in the specialized literature are used to verify studies regarding power system planning or network reliability. However, there are no test systems currently available with enough information in order to endorse studies that simultaneously approach expansion planning, operation, and reliability issues. This paper introduces a real test system, including the load modeling, and generation and transmission systems. The main objective is to provide all the details and information required to evaluate methods and models developed for power system planning, operation, and reliability. The presented load modeling includes hourly, daily, weekly, monthly, and seasonal patterns. Furthermore, besides the substation data, reliability details, construction costs, and characteristics of right of ways (e.g., line length, impedance, and ratings) for the transmission system are exposed. The real transmission system presented contains 39 buses, 135 transformers, and 66 lines at two voltage levels: 230 and 400 kV. Finally, the generation system reliability data as well as operation and installation costs for each unit are also provided.

Keywords Network reliability · Power system operation · Power system planning · Real test system

1 Introduction

Interests in studying reliability and operation issues together with power system planning have increased due to the important role played by these areas in the generation and transmission capacity expansion. For reliability studies, test systems such as the RBTS (Billinton 1989), IEEE RTS (IEEE Reliability Test System 1979), and Korean southeast power system (Choi et al. 2006) have been introduced. On the other hand, Garver's network (Garver 1970), Brazilian 46-, 78-, and 87-bus interconnections (Romero and Monticelli 1994; Romero et al. 2002), Colombian network (Escobar 2002; Escobar et al. 2004), IEEE 24-, 25-, and 30-bus systems (Ekwue and Cory 1984; Fang and Hill 2003; Tor et al. 2010), Portuguese generation/transmission network (Braga and Saraiva 2005), and Iranian 18-bus regional and 400 kV national grids (Shayeghi and Mahdavi 2009; Maghouli et al. 2011) have been used for planning case studies. However, none of these case studies provides a simultaneous comparison of the results obtained using different methods of planning, operation, and reliability. Thus, it is desirable to have a reference test system that incorporates the real basic data needed in power system planning, operation, and reliability evaluation.

In existing test systems, the whole set of parameters needed for both planning and reliability applications is not provided. For example, Garver's network and other case studies about power system planning (Garver 1970; Romero and Monticelli 1994; Romero et al. 2002; Escobar 2002; Escobar et al. 2004; Ekwue and Cory 1984; Fang and Hill 2003; Tor et al. 2010; Braga and Saraiva 2005; Shayeghi and Mahdavi 2009; Maghouli et al. 2011) do not contain reliability and operation details. Moreover, reliability test systems as reported in (Billinton 1989; IEEE Reliability Test System 1979; Choi et al. 2006) do not include configuration and complete reliability information about substations [e.g., number, age and capacity of transformers at each bus, as well as their forced outage rate (FOR), forced outage duration (FOD),

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Table 1 Seasonal peak load as percentages of annual peak

Season (%)	Winter (%)	Spring (%)	Summer (%)	Autumn (%)
Peak load	91.3	90.6	100	90.2

Table 2 Monthly peak load as percentages of seasonal peak

Season	Month	Peak load (%)	Season	Month	Peak load (%)
Winter	Jan.	99.3	Summer	Jul.	98.2
	Feb.	97.8		Aug.	100
	Mar.	100		Sep.	94.1
Spring	Apr.	85.9	Autumn	Oct.	100
	May	90.4		Nov.	89.6
	Jun.	100		Dec.	88.5

Table 3 Weekly peak load as percentages of annual peak (%)

W.	Peak load	W.	Peak load	W.	Peak load	W.	Peak load	W.	Peak load	W.	Peak load	W.	Peak load	W.	Peak load
1	81.5	8	82.2	15	75.9	22	85	29	99.2	36	94	43	77.6	50	81.65
2	81.8	9	81.7	16	77.2	23	88.6	30	98.4	37	92.6	44	80	51	81.5
3	80	10	81.35	17	79	24	90.7	31	99	38	91	45	80.5	52	81.2
4	81.2	11	81.95	18	80	25	93.8	32	100	39	90.2	46	80	–	–
5	81.5	12	75.6	19	82	26	93.2	33	98.95	40	85.7	47	80.4	–	–
6	79.4	13	67.85	20	83.2	27	96.1	34	97.9	41	84.6	48	79.9	–	–
7	81.4	14	74.4	21	85.8	28	97.3	35	96	42	81.8	49	80.6	–	–

and scheduled outage duration (SOD)]. Furthermore, data on future expansion (e.g., load growth and lengths of new right of ways considering geographical limitations), actual location of buses, line characteristics (e.g., bundled conductors and line types), reliability and construction costs, daily peak loads, load diversity between buses, and scheduled outages of transmission lines such as repair rate and mean time to repair (MTTR) were also ignored. Besides, data regarding equipment age and substations configurations, which have important effects on planning decisions (Mahdavi et al. 2016), have not been considered by proposed test systems such as RTS. Reliability parameters such as generators forced and scheduled outage duration, lines MTTR and repair rate, and transformers forced and scheduled outages could efficiently affect proposed expansion plans. However, these essential data have not provided by RTS and other reliability test systems.

The main contribution of this work is to provide all the details and information required to evaluate methods and models developed for power system planning, operation, and reliability; i.e., gathering the different data required for studying an experimental power system from various aspects. It describes the reliability data, generation system characteristics, and transmission network details. This paper provides essential data on the expansion, operation, and reliability of an actual power system, which is part of the Iranian north interconnected network and well-known as the regional electric company of Tehran (RECT). All expansion, operation, and reliability data, except for lost load and energy costs, are representative of the experiences of the RECT. The values for lost loads and costs of energy not supplied are based on reliability data from Canada, because such expenses have not yet been calculated in Iran. This case study does not include distribution system configuration or protective relays data, because the aim is to define a system that is broad enough to provide a basis for reporting on analysis methods for combined generation/transmission expansion planning with composite power system reliability.

2 Description of Test System

2.1 Load Characteristics

The annual peak load for the test system is 10729 MW. Table 1 describes the peak loads as a percentage of the annual

Table 4 Daily peak load as percentages of weekly peak (%)

Days	Week number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Mon	98.6	100	99.95	99.4	100	100	98.2	100	98.3	99.5	100	100	100
Tue	98.3	97.4	99.6	99.8	99	94.95	98.9	98.6	99.1	98.5	98.2	80.4	99.795
Wed	99.3	89.4	98.7	99.8	99.4	82.1	98.6	99.5	99.3	99.4	97.6	83.6	99.4
Thu	95	92.6	91.2	94.7	95.3	80.3	95.2	94.4	95.5	96.6	95.3	83.9	99.2
Fri	90.3	87.8	89.7	89.5	90	88.6	90.5	89.7	92.8	92.35	91	83.8	96
Sat	99.1	96.2	99.9	98.8	97.8	92.6	99.5	97.75	100	100	94.7	85.1	95.4
Sun	100	96.6	100	100	96.6	99.3	100	97.9	98.5	99.4	93.2	89.6	93.5
Days	14	15	16	17	18	19	20	21	22	23	24	25	26
Mon	98	99.5	99.1	98.5	98.3	96.75	97.8	95.5	99.6	93.97	96	98.3	99.8
Tue	98	98	100	100	100	97.65	97.5	96.6	97.4	100	98.6	99.5	96.6
Wed	98.8	99.9	98.6	95.3	98	98.5	100	96.45	99.7	98	98.2	99.2	97.5
Thu	100	96.7	99.6	98	98	96.5	99.7	97.1	100	95.9	89.1	99.5	98.8
Fri	96.45	97.5	98.6	97.6	95.4	98.4	97	93.9	98.95	94.6	98.2	94.2	95.2
Sat	90.6	95	95.3	91.5	89.4	93	92	91.8	93.8	91.9	95.2	92.6	92.9
Sun	95.7	100	99.9	98.7	96.4	100	98.65	100	95.3	98.7	100	100	100
Days	27	28	29	30	31	32	33	34	35	36	37	38	39
Mon	98.6	95.1	100	97.9	100	100	98.65	98.8	100	99.45	100	100	99
Tue	98.1	99.6	99.7	98.95	99.7	99.2	99.65	98.5	99.5	100	99.8	98.7	100
Wed	100	94.8	98.9	98.5	98.35	98.3	100	98.7	96	97.5	98.9	93.345	98.2
Thu	99.9	98.4	97.6	98.6	98.9	97	97.7	96	95.7	97.3	98.4	99.1	96
Fri	96.6	97.3	95.75	96.5	95	96	95.65	90.9	93.4	93.5	94.3	96.945	92.7
Sat	92.9	93.8	91.1	92.4	93.65	89.9	95.8	90.9	90.7	89.8	89.7	91.9	88.1
Sun	97.5	100	97.7	100	98.7	97.1	99.8	98	98.8	98.6	97.7	99.9	95.3
Days	40	41	42	43	44	45	46	47	48	49	50	51	52
Mon	100	98.9	99.6	99.1	97.5	99.8	98.35	99	96.9	99	99.1	99.2	98.3
Tue	100	98.5	98.9	94.2	96.8	100	98.6	97.7	91.6	100	100	100	98
Wed	99.3	100	99	89	93.8	97.3	99.1	97.8	98	99.8	99.4	99.7	98.9
Thu	97.8	99.4	100	98.4	96.3	98	98.4	99.7	99.25	99.8	99	96.85	100
Fri	95.8	96	95.5	95.25	94.2	94.6	95.75	96.4	95.9	96.2	96.4	88.9	95.84
Sat	91.5	91	89.7	92.95	87.4	89.25	89.9	88.3	90.3	88.5	88.9	90	89.1
Sun	99.2	96.4	95.7	100	100	98.6	100	100	100	99.8	99.9	98.1	99.45

peak load for each season. This table is helpful for multi-stage power system expansion planning when the planners consider a multi-level load for the electrical power demand. Table 2 shows monthly peak loads as a percentage of the seasonal peak loads for each month.

Three months in every season have been normalized with respect to the peak load of the corresponding season. For example, the peak load of January is stated as a percentage of winter peak load, and July is represented as a percentage of summer peak. Table 3 gives data on weekly peak loads as percentages of the annual peak load. Week 1 is taken the first week in January. The annual peak occurs at week 32. Table 4 lists daily peak loads as percentages of the weekly peak. The data in Table 4 define a daily peak load model of $52 \times 7 = 364$ days, with Monday as the first day of the year.

Table 5 gives hourly load models for each of the four seasons. The first column reflects winter, while the second, third, and fourth columns indicate spring, summer, and autumn, respectively. Combining Tables 3, 4, and 5 with the annual peak load generates an hourly load model of $364 \times 24 = 8736$ h. In simple terms, the annual load curve for 8736 hours is available and the planners can determine minimum and maximum load level in every day, week, month, season or year.

Table 5 Hourly load as percentages of daily peak (%)

Hour	Winter	Spring	Summer	Autumn
1	73	81	83.7	75
2	70	78.7	80.3	73.5
3	68	74	77.9	71
4	69	70	75.6	69
5	70	69	75	70
6	74	70.5	74.4	71.5
7	78	70	70.9	72
8	72	75	70.3	79
9	78	81	73.8	84
10	79	85	77.9	89
11	80	88	81.4	90
12	85	90	85.5	91.5
13	85	89	88.3	91
14	80	86	89.5	88
15	81	84	90.7	81.5
16	87	87	91.3	83
17	98	92	90.7	93
18	100	96	87.2	96
19	99	98	82.5	100
20	98	100	83	98
21	98.5	98.5	96	97
22	94	97	100	96
23	89	96	97	85
24	80	87	92.5	81

Minimum load would be useful for demand response and peak load shifting studies. The annual load factor for this model is 65. The annual load factor is equal to the annual average demand divided by the annual peak load.

2.2 Generation System

Table 6 lists the generating unit ratings, the reduced-capacity duration (RCD), and reliability data (such as FOR, mean time to failure (MTTF), MTTR, FOD, and SOD), where RCD is the time that a generating unit is operated in derated state and can deliver partial output. FOD is the average time taken to repair the failed unit, i.e., FOD refers to the time necessary to execute corrective repairs, due to unexpected failures in a generating unit. On the other hand, SOD is the average duration of the time necessary to execute preventive repairs (maintenance), i.e., the generating unit was still working but a scheduled withdraw is done to correct specific defects in order to avoid forced outages (Mahdavi et al. 2017).

Table 7 gives the operating data for the generating units, while the unit size and operating output of the generation mix are shown in Table 8. Table 9 gives the ages and the installation costs of the generating units for maintenance and planning applications. Moreover, fuel costs are suggested in Tables 10 and 11. These costs are subject to variation due to geographical location and other factors. Thus, in Table 10, nodal fuel transportation costs for power production are given.

Finally, the generating unit operating costs (OCs), commonly used in economic dispatch studies, can be calculated using the information presented in Tables 7, 10, 11, and 12. The calculation of the OCs is shown in (1), in terms of the fuel rate (FR; fourth column of Table 7), the heat rate (HR; sixth column of Table 7), the Transportation Cost (TC; third column of Table 10), the Toll (fourth column of Table 10), and the Price (second column of Table 11). Further information regarding capacity outage for the generating units is presented as an "Appendix".

$$\mathrm{OC} = \mathrm{FR} \times \mathrm{HR} \times (\mathrm{TC} + \mathrm{Toll} + \mathrm{Price}) \quad (1)$$

2.3 Transmission Network

The transmission network consists of 39 bus locations connected by 66 lines as shown in Fig. 1. The transmission lines are at two voltage levels: 230 and 400 kV. The locations of the generating units are shown in Table 12. Moreover, Table 12 shows the number of existing units in each generation bus and the maximum number of units (i.e., the sum of existing units and new units that can be installed in each generation bus).

It can be seen that 13 out of the 39 buses are generating stations. Moreover, buses 7 and 32 are connected to the Iranian Interconnected Network (which is a large transmission system with more than 200 buses); hence, they are considered slack buses. Table 13 provides data on generating unit reactive power capability for use in AC load flow calculations. Table 14 gives the reactive capability of voltage corrective devices. These devices help the system to maintain its rated voltage under contingency conditions. In addition, the annual peak load of the system is shown in Table 15.

In Table 15, the load diversity between buses is provided by load type. Load types 1, 2, 3, 4, and 5 indicate domestic, public, agricultural, industrial, and commercial demands, respectively. Moreover, substation characteristics, such as the number and capacity of each transformer, and their reliability data are given in Table 16. It is important to remark that the reliability information presented in Table 16 includes all the devices within the substation (e.g., transformers, capacitors, and reactors). In buses with the two transmission voltage levels (5, 8, 12, 13, 19, 25, and 27), loads are connected to the 63 kV side. The value of lost load (VOLL) and cost of energy not supplied (cost of ENS) for each load type are given in Table 17. The VOLL of each bus was obtained by combining the data in Table 15 with Table 17. For example, the VOLL of bus 1 is equal to $0.5 \times 150 + 0.28 \times 500 + 0.02 \times 3500 +$

Table 6 Generating unit reliability data

Unit size (MW)	No. of units	FOR	MTTF (h)	MTTR (h)	FOD (h)	SOD (h)	RCD (h)
12.5	4	0.036	1607	60	6	14	2553
23.7	16	0.17	244	50	4.5	16	2941
24	4	0.073	1016	80	13	20	6031
25	5	0.17	195	40	6	9.5	2941
32	13	0.17	146.5	30	7	8.5	2941
38.5	3	0.072	902	70	10	22	6031
82.5	3	0.08	460	40	6.5	8.5	1920
85	3	0.017	2024	35	4	11	2941
100	2	0.06	1097	70	3	4	1004
102	3	0.019	2840	55	14.5	30	1655
105	3	0.017	3469	60	6	13	2070
116.2	6	0.019	1549	30	5	17	1655
123.8	6	0.17	220	45	7	9	2070
128.5	4	0.06	940	60	3	3	1004
156.5	4	0.09	607	60	4	4	1090
159	12	0.022	1778	40	8	22	2930
161	4	0.15	340	60	8	15	5324
166	5	0.04	960	40	8	10	980
250	4	00.005	7960	40	11	3.8	2070
263	3	0.09	708	70	3	7	1050
318	5	0.035	2206	80	10	18	3240
322	1	0.15	567	100	10	20	980
332	1	0.04	2400	100	10	20	5324
526	3	0.095	1429	150	10	30	1050

$0.09 \times 1500 + 0.11 \times 4500 = 915$ \$/MW. The cost of ENS for bus 39 is 4.17 \$/kWh ($0.455 \times 0.56 + 0.15 \times 1.45 + 0.05 \times 14 + 0.245 \times 5.5 + 0.1 \times 16.5$). Furthermore, Table 18 illustrates the average annual load growth of each bus.

Figure 1 defines the actual geographical connections for the transmission network. The line lengths, which are shown in Tables 19 and 20, determine the physical bus locations in Fig. 1. Table 19 includes the number of circuits and bundled conductors, line voltage levels and types, transmission reliability data, and line ages for an actual network.

Line ages show when a transmission line was constructed in the network. Types 1, 2, and 3 indicate Canary, Cardinal, and Curlew conductors, while type 4 explains that the connection between the two buses is provided by cables. The length of each corridor is not a direct route between two buses. All distances have been calculated considering geographical limitations such as hills, forests, parks, roads, highways, farms, and other barriers. Table 20 gives the practical lengths of all candidate corridors for transmission network expansion, considering geographical restrictions. Impedance, rating data and construction cost for the lines are listed in Table 21.

The RECT system represents the 23 and 20% of the Iranian interconnected network total generation and consumption, respectively. Besides, its transmission and distribution power losses are 3.5 and 13.5% of the interconnected network power losses, respectively. The RECT system is the first ranked network in power generation and demand among all regional electric companies in Iran. In addition, each year the RECT system sales 5966 MWh and buys 3777 MWh to/from the interconnected network. Furthermore, annual average outage durations of 400 and 230 kV lines in RECT system are 7.2 and 7.7 h, respectively. Finally, average duration of each outage for 400 and 230 kV substations in RECT system is 5.9 and 30.5 h, respectively.

3 Conclusion

A real test system known as regional electric company of Tehran (RECT) system, which is part of the Iranian north interconnected network, has been presented in this work, including the reliability data, generation system characteristics, and transmission network details. The presented data allow to incorporate various real parameters into experimental integrated models, contributing to the research on power

Table 7 Generating unit operating data

Size MW	Type	Fuel type	Fuel rate lit/kcal	Max. output MW	Heat rate kcal/kW
12.5	Fossil	Oil	1.0114	10	3958
	Steam				
23.7	Comb.	Oil	0.8566	20	3702
	Turbine	Gasoil	0.1463		
24	Hydro	–	–	24	–
25	Comb.	Oil	0.8566	20	3702
	Turbine	Gasoil	0.1463		
32	Comb.	Oil	0.8566	26	3702
	Turbine	Gasoil	0.1463		
38.5	Hydro	–	–	38.5	–
82.5	Fossil	Gasoil	0.0073	75	2960
	Steam	Gas	0.7356*		
		Oil	0.237		
85	Comb.	Oil	0.8566	70	3702
	Turbine	Gasoil	0.1463		
100	Combined	Gasoil	0.093	100	1874
	Cycle	Gas	0.9123*		
102	Combined	Gasoil	1.481	100	1875
	Cycle	Gas	0.853*		
105	Combined	Gasoil	0.0763	100	1987
	Cycle	Gas	0.93*		
116.2	Combined	Gasoil	1.481	96.5	1875
	Cycle	Gas	0.853*		
123.8	Combined	Gasoil	0.0763	100	1987
	Cycle	Gas	0.93*		
128.5	Combined	Gasoil	0.093	106	1874
	Cycle	Gas	0.9123*		
156.5	Fossil	Gasoil	0.0075	150	2502
	Steam	Gas	0.642*		
		Oil	0.319		
159	Comb.	Oil	0.77	135	3063
	Turbine	Gasoil	0.231		
161	Combined	Gasoil	0.0898	160	1850
	Cycle	Gas	0.662*		
166	Comb.	Oil	0.395	160	3500
	Turbine	Gasoil	0.0576		
250	Fossil	Gasoil	0.00007	250	2124
	Steam	Gas	0.661*		
		Oil	0.31		
263	Comb.	Oil	0.149	250	3700
	Turbine				
318	Comb.	Oil	0.631	300	4000
	Turbine				
322	Combined	Gasoil	0.0898	320	1850
	Cycle	Gas	0.662*		
332	Comb.	Oil	0.395	320	3500
	Turbine	Gasoil	0.0576		
526	Comb.	Oil	0.149	500	3700
	Turbine				

* m_3/kcal

Table 8 Generation mix

Type	Unit size (MW)	Operating output (MW)
Fossil steam	1923.5	1865
Combustion turbine	8202.2	7458
Combined cycle	3741	3363
Hydro	211.5	211.5
Total	14,078.2	12897.5

Table 9 Unit ages (year) and installation costs (Million$)

Size MW	Age	Cost	Size MW	Age	Cost
12.5	56	10	123.8	21	111
23.7	37	20	128.5	22	116
24	9	14	156.5	42	125
25	37	21	159	10	135
32	37	27	161	6	145
38.5	27	23	166	6	141
82.5	47	66	250	23	200
85	37	72	263	8	224
100	17	90	318	9	270
102	15	92	322	6	290
105	14	95	332	5	282
116.2	23	105	526	8	447

Table 10 Fuel expenses

Bus	Fuel	Transportation cost	Toll
4	Gas	0.000004 ($/m^3)	0.000058 ($/m^3)
	Gasoil	0.0000078 ($/lit)	0.00011 ($/lit)
7	Gas	0.0000052 ($/m^3)	0.000058 ($/m^3)
	Oil	0.0000049 ($/lit)	0.000055 ($/lit)
	Gasoil	0.0000097 ($/lit)	0.00011 ($/lit)
10	Gas	0.0000035 ($/m^3)	0.000093 ($/m^3)
	Oil	0.0000033 ($/lit)	0.000089 ($/lit)
	Gasoil	0.0000066 ($/lit)	0.00018 ($/lit)
11	Gas	0.0000035 ($/m^3)	0.000093 ($/m^3)
	Gasoil	0.0000066 ($/lit)	0.00018 ($/lit)
17	Oil	0	0
23	Gas	0.0000067 ($/lit)	0.000054 ($/m^3)
	Oil	0.0000064 ($/lit)	0.000052 ($/lit)
	Gasoil	0.000013 ($/lit)	0.0001 ($/lit)
30	Oil	0.0000083 ($/lit)	0.00013 ($/lit)
31	Oil	0.0000088 ($/lit)	0.00013 ($/lit)
	Gasoil	0.0000057 ($/lit)	0.00026 ($/lit)
32	Oil	0.00000324 ($/lit)	0.000095 ($/lit)
	Gasoil	0.00000647 ($/lit)	0.000187 ($/lit)
33	Gas	0.0000038 ($/m^3)	0.00011 ($/m^3)
	Gasoil	0.0000076 ($/lit)	0.00022 ($/lit)
34	Oil	0.0000036 ($/lit)	0.00011 ($/lit)
	Gasoil	0.0000072 ($/lit)	0.0002 ($/lit)
36	Oil	0.0000039 ($/lit)	0.00011 ($/lit)

Table 11 Fuel prices

Fuel	Price
Gas	0.00307 ($/m^3)
Oil	0.00293 ($/lit)
Gasoil	0.00586 ($/lit)

Table 12 Generating unit locations

Bus	Size (MW)	No. of existing units	Max. number of units
4	161	4	8
	322	1	5
6	24	4	8
	38.5	3	6
7	105	3	6
	123.8	6	10
	250	4	8
10	156.5	4	8
11	102	3	6
	116.2	6	10
17	12.5	4	8
23	82.5	3	6
30	318	5	8
31	23.7	16	20
	25	5	8
	32	13	16
	85	3	6
32	159	12	16
33	100	2	5
	128.5	4	8
34	166	5	8
	332	1	5
36	263	3	6
	526	3	6

system expansion planning, operation, and reliability. Due to their small size, widely known test systems (e.g., Garver's network and RBTS) may not adequately show the accuracy of proposed models. On the other hand, due to lack of information, larger test systems (e.g., RTS and Brazilian interconnections) may not be of use to authors of technical papers. Thus, the complete set of information exposed makes the presented test system highly useful to researchers in order to demonstrate robustness and effectiveness of proposed methodologies, evaluating present and future scenarios in the power system considering reliability and economic aspects.

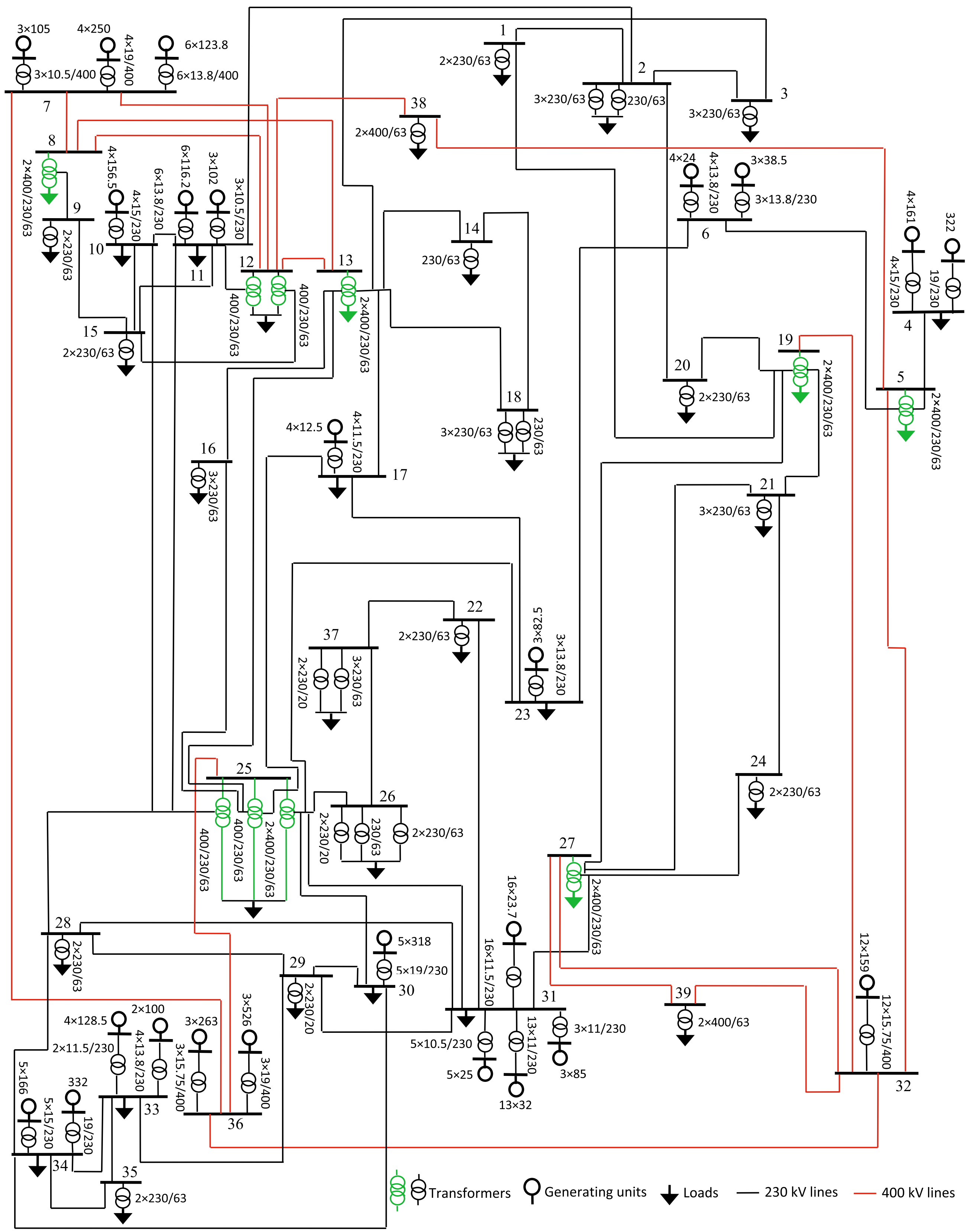

Fig. 1 RECT system

Table 13 Generating unit reactive capability

Unit size (MW)	MVAr		Unit size (MW)	MVAr	
	Min	Max		Min	Max
12.5	0	8	123.8	− 25	60
23.7	0	10	128.5	0	40
24	0	10	156.5	0	25
25	0	10	159	0	85
32	− 10	15	161	0	85
38.5	− 10	15	166	− 20	45
82.5	0	35	250	− 40	130
85	− 25	35	263	0	70
100	− 25	30	318	− 25	90
102	0	45	322	− 50	170
105	− 30	50	332	0	90
116.2	− 35	55	526	− 50	150

Table 14 Voltage correction devices

Bus	Device	Amount of devices	Capability of each device (MVAr)	Total capability (MVAr)	Failure rate (h)	MTTR (h)	FOD (h)
2	Capacitor	2	20	40	0.2	20	2
3	Capacitor	2	20	40	0.22	18	1.8
8	Reactor	4	25	100	0.16	24	0.7
10	Capacitor	2	20	40	0.25	26	0.9
12	Reactor	1	25	25	0.15	25	0.6
16	Capacitor	2	10	20	0.22	32	1.5
17	Capacitor	2	20	40	0.28	16	2.5
19	Reactor	4	25	100	0.14	20	0.2
21	Capacitor	2	20	40	0.18	28	0.7
27	Reactor	2	25	50	0.14	30	1.4
32	Reactor	3	50	150	0.17	35	0.8
36	Reactor	2	50	100	0.16	22	0.3

Table 15 Bus load data

Bus	Load		Portion of load type from active bus load %				
	MW	MVAr	Type				
			1	2	3	4	5
1	138	34	50	28	2	9	11
2	211	70	50	28	2	9	11
3	339	250	50	28	2	9	11
4	66	29	50	28	2	9	11
5	125	57	50	28	2	9	11
8	550	260	40	31	0.04	15	14
9	190	68	40	31	0.04	15	14
10	350	175	40	31	0.04	15	14
11	170	96	40	31	0.04	15	14
12	290	200	40	31	0.04	15	14
13	620	350	40	31	0.04	15	14
14	34	20	40	31	0.04	15	14
15	290	154	40	31	0.04	15	14

Table 15 continued

Bus	Load		Portion of load type from active bus load %				
	MW	MVAr	Type				
			1	2	3	4	5
16	354	210	39	20.5	5.5	30	5
17	234	90	39	20.5	5.5	30	5
18	480	220	50	28	2	9	11
19	800	280	50	28	2	9	11
20	210	116	50	28	2	9	11
21	315	219	50	28	2	9	11
22	168	96	40.5	28.5	0	4	27
23	175	9	40.5	28.5	0	4	27
24	206	116	45.5	15	5	24.5	10
25	780	260	39	17	5.5	30	8.5
26	746	390	40.5	28.5	0	4	27
27	720	360	45.5	15	5	24.5	10
28	268	114	42	16	2.5	24	15.5
29	6	1	42	16	2.5	24	15.5
30	230	92	42	16	2.5	24	15.5
31	278	42	42	16	2.5	24	15.5
33	128	42	37.5	13.5	15.5	26	7.5
34	240	150	37.5	13.5	15.5	26	7.5
35	64	20	37.5	13.5	15.5	26	7.5
37	404	268	40.5	28.5	0	4	27
38	250	120	40	31	0.04	15	14
39	300	144	45.5	15	5	24.5	10
Total load		10729 MW			5122 MVAr		

Table 16 Substation data: capacity and reliability

Bus	Voltage (kV)	Capacity of transformers (MVA)	Failure rate (1/year)	Failure duration (h)	Repair rate (1/year)	Repair duration (h)	Age (year)
1	230/63	2 × 160	0.96	4.5	7	8	13
2	230/63	1 × 80	0.9	9.5	11	9	42
		3 × 90	0.8	8	12	7	42
3	230/63	3 × 180	0.85	5.5	9	7	42
4	15/230	4 × 200	0.75	6.5	15	6	20
	19/230	1 × 350	0.75	6.5	15	6	20
5	400/230/63	2 × 500	0.1	2	6.5	6.5	7
6	13.8/230	7 × 40	0.75	6.5	15	6	27
7	10.5/400	3 × 125	0.1	2	6.5	6.5	14
	13.8/400	6 × 154	0.1	2	6.5	6.5	21
	19/400	4 × 312.5	0.1	2	6.5	6.5	23
8	400/230/63	2 × 500	0.05	3	5	8	37
9	230/63	2 × 160	0.96	4.5	7	8	14
10	15/230	4 × 160	0.7	5	6	10	45
11	13.8/230	6 × 140	0.7	5	6	10	13
	10.5/230	3 × 125	0.7	5	6	10	13

Table 16 continued

Bus	Voltage (kV)	Capacity of transformers (MVA)	Failure rate (1/year)	Failure duration (h)	Repair rate (1/year)	Repair duration (h)	Age (year)
12	400/230/63	1 × 500	0.05	3	5	8	13
		1 × 500	0.05	3	5	8	10
13	400/230/63	2 × 500	0.05	3	5	8	40
14	230/63	1 × 160	0.96	4.5	7	8	15
15	230/63	2 × 250	0.7	5	6	10	10
16	230/63	3 × 180	0.85	5.5	9	7	40
17	11.5/230	4 × 35	0.828	6.5	10	7.8	44
18	230/63	3 × 180	0.85	5.5	9	7	26
		1 × 180	0.85	5.5	9	7	11
19	400/230/63	2 × 500	0.05	3	5	8	35
20	230/63	2 × 160	0.96	4.5	7	8	17
21	230/63	3 × 180	0.85	5.5	9	7	41
22	230/63	2 × 180	0.85	5.5	9	7	16
23	13.8/230	3 × 100	0.1	2	6.5	6.5	49
24	230/63	2 × 160	0.96	4.5	7	8	18
25	400/230/63	2 × 500	0.05	3	5	8	34
		1 × 500	0.05	3	5	8	14
		1 × 500	0.05	3	5	8	7
26	230/63	2 × 180	0.85	5.5	9	7	25
	230/63	1 × 180	0.85	5.5	9	7	10
	230/20	2 × 90	0.8	8	12	7	25
27	400/230/63	2 × 500	0.05	3	5	8	29
28	230/63	2 × 160	0.96	4.5	7	8	21
29	230/20	2 × 40	0.75	6.5	15	6	12
30	19/230	5 × 350	0.7	5	6	10	13
31	11.5/230	16 × 35	0.7	5	6	10	33
	10.5/230	5 × 35	0.7	5	6	10	33
	11/230	13 × 40	0.7	5	6	10	33
	11/230	3 × 110	0.7	5	6	10	33
32	15.75/400	12 × 200	0.1	2	6.5	6.5	41
33	11.5/230	2 × 137.5	0.7	5	6	10	38
	13.8/230	4 × 126	0.7	5	6	10	38
34	15/230	5 × 200	0.7	5	6	10	21
	19/230	1 × 350	0.7	5	6	10	21
35	230/63	2 × 40	0.75	6.5	15	6	11
36	15.75/400	3 × 312.5	0.1	2	6.5	6.5	31
	19/400	3 × 550	0.1	2	6.5	6.5	31
37	230/63	3 × 180	0.85	5.5	9	7	21
	230/20	2 × 90	0.8	8	12	7	21
38	400/63	2 × 200	0.15	1	8	5	6
39	400/63	2 × 200	0.15	1	8	5	7

Table 17 Costs of lost load and energy

Load type	1	2	3	4	5
VOLL ($/MW)	150	500	3500	1500	4500
Cost of ENS ($/kWh)	0.56	1.45	14	5.5	16.5

Table 18 Load growth data (%)

Bus	Load type				
	1	2	3	4	5
1	6.2	9.3	7.6	2	14
2	6.2	9.3	7.6	2	14
3	6.2	9.3	7.6	2	14
4	6.2	9.3	7.6	2	14
5	6.2	9.3	7.6	2	14
8	3.9	7.9	17	4.8	13
9	3.9	7.9	17	4.8	13
10	3.9	7.9	17	4.8	13
11	3.9	7.9	17	4.8	13
12	3.9	7.9	17	4.8	13
13	3.9	7.9	17	4.8	13
14	3.9	7.9	17	4.8	13
15	3.9	7.9	17	4.8	13
16	9.3	10	9.5	8.3	8.6
17	9.3	10	9.5	8.3	8.6
18	6.2	9.3	7.6	2	14
19	6.2	9.3	7.6	2	14
20	6.2	9.3	7.6	2	14
21	6.2	9.3	7.6	2	14
22	3.2	18	0	6.6	6
23	3.2	18	0	6.6	6
24	6.1	8.3	14	5.8	7.2
25	9.3	10	9.5	8.3	8.6
26	3.2	18	0	6.6	6
27	6.1	8.3	14	5.8	7.2
28	6.4	2.8	4.8	7	7.1
29	6.4	2.8	4.8	7	7.1
30	6.4	2.8	4.8	7	7.1
31	6.4	2.8	4.8	7	7.1
33	11	15	5.4	10	8
34	11	15	5.4	10	8
35	11	15	5.4	10	8
37	3.2	18	0	6.6	6
38	3.9	7.9	17	4.8	13
39	6.1	8.3	14	5.8	7.2

Table 19 Transmission line data

Corr	Length (km)	Number of circuits	Number of bundled conductors	Type	Voltage (kV)	Failure rate (1/year)	Failure duration (h)	Repair rate (1/year)	Repair duration (h)	Age (year)
1–2	9.5	1	2	1	230	0.15	4	0.3	11	13
1–19	21.5	1	2	1	230	0.3	4	0.33	11	13
2–3	17	1	2	1	230	0.26	4	0.33	11	40
2–11	55	1	2	1	230	0.85	6	0.4	15	19
2–20	15	1	2	1	230	0.23	4	0.32	11	18
3–13	30	1	2	1	230	0.46	4	0.35	11	19
4–5	20	1	1	1	230	0.3	3	0.33	10	10
5–6	9	1	1	1	230	0.14	3	0.31	10	11
5–32	75	2	3	3	400	0.7	11	0.52	35	9
5–38	50	2	3	3	400	0.47	9	0.47	25	8
6–23	53	2	1	1	230	0.8	5	0.4	12	30
7–8	25	2	3	3	400	0.23	6	0.43	15	26
7–12	110	2	3	3	400	1.03	13	0.59	40	7
7–36	110	2	3	3	400	1.02	13	0.58	40	16
8–9	33	1	1	2	230	0.5	3	0.36	10	14
8–12	82	1	3	3	400	0.77	11	0.53	35	14
8–13	101	1	3	3	400	0.95	11	0.57	35	16
9–15	23	1	1	2	230	0.35	3	0.34	10	14
10–11	3	2	2	1	230	0.05	4	0.3	11	20
10–15	18	1	1	2	230	0.27	3	0.33	10	21
10–25	31	1	2	1	230	0.48	4	0.35	11	40
11–12	18	2	2	1	230	0.27	4	0.33	11	13
11–15	17	1	2	1	230	0.26	4	0.33	11	8
11–25	28	1	1	1	230	0.43	3	0.35	10	49
12–13	17	2	2	3	400	0.26	4	0.33	11	14
12–15	7	1	2	1	230	0.11	4	0.3	11	8
12–38	25	2	3	3	400	0.23	6	0.43	15	9
13–14	10	1	2	2	230	0.15	4	0.31	11	8
13–16	11	1	2	1	230	0.17	4	0.31	11	40
13–17	8	2	2	1	230	0.12	4	0.31	11	40
13–18	14	1	2	2	230	0.21	4	0.32	11	15
13–25	24	1	2	1	230	0.37	4	0.34	11	40
14–18	7	1	2	2	230	0.11	4	0.33	11	8
16–25	13	1	2	1	230	0.2	4	0.32	11	40
17–23	15	1	1	1	230	0.23	4	0.32	11	7
17–25	14	2	1	1	230	0.21	3	0.32	10	10
19–20	9	1	2	1	230	0.13	4	0.31	11	18
19–21	8	1	2	1	230	0.12	4	0.12	11	41
19–27	32	1	2	1	230	0.49	4	0.36	11	18
19–32	62	2	3	3	400	0.58	9	0.5	25	12
21–27	27	1	2	1	230	0.42	4	0.35	11	16
21–24	9	1	1	1	230	0.13	4	0.31	11	1
22–31	19	1	1	2	230	0.29	3	0.33	10	17
22–37	4.5	–	–	4	230	0	0	0.2	16	11
23–25	15	2	1	1	230	0.23	3	0.32	10	49
24–27	20	2	2	1	230	0.31	4	0.33	11	17

Table 19 continued

Corr	Length (km)	Number of circuits	Number of bundled conductors	Type	Voltage (kV)	Failure rate (1/year)	Failure duration (h)	Repair rate (1/year)	Repair duration (h)	Age (year)
25–26	6	2	2	2	230	0.09	4	0.3	11	29
25–28	11.5	1	1	2	230	0.18	3	0.31	10	11
25–30	40	2	2	2	230	0.62	6	0.37	15	7
25–31	15	1	1	2	230	0.23	3	0.32	10	11
25–36	46	2	3	3	400	0.43	9	0.47	25	34
26–37	12	–	–	4	230	0	0	0.25	16	11
27–31	17	2	1	1	230	0.26	3	0.33	10	29
27–32	28	1	2	3	400	0.26	5	0.43	12	15
27–39	18	1	2	3	400	0.17	5	0.41	12	7
28–29	18	1	1	1	230	0.28	3	0.33	10	12
28–31	21.5	1	1	2	230	0.33	3	0.33	10	11
28–34	120	1	1	1	230	1.85	8	0.54	20	4
29–30	13	1	1	1	230	0.2	3	0.32	10	12
29–31	38	1	1	1	230	0.58	5	0.37	12	12
29–33	115	1	1	1	230	1.77	7	0.53	18	12
30–34	145	1	1	1	230	2.23	8	0.6	20	12
32–36	100	2	3	3	400	0.93	10	0.56	309	34
32–39	18	1	2	3	400	0.17	5	0.41	12	7
33–34	20	3	2	1	230	0.31	4	0.33	11	22
33–35	40	2	1	1	230	0.61	5	0.37	12	9
34–35	30	1	1	1	230	0.46	4	0.35	11	2

Table 20 Corridor length

Corr	Length (km)	Corr	Length (km)	Corr	Length (km)	Corr	Length (km)	Corr	Length (km)	Corr	Length (km)
1–3	22	2–14	15	6–13	55	10–12	19	13–39	12	25–29	30
1–4	70	2–18	14	6–14	8	10–13	25	14–17	14	25–37	14
1–5	65	2–19	10	6–18	10	10–16	25	14–19	18	26–27	10
1–6	12	2–21	10	6–19	6	10–26	42	14–20	13	26–28	8
1–8	100	3–4	55	6–20	7	10–28	40	14–37	14	26–29	12
1–9	60	3–5	65	7–13	127	11–13	26	14–38	6	26–30	15
1–10	52	3–6	7	7–23	60	11–14	33	15–16	25	26–33	120
1–11	50	3–8	41	7–25	47	11–16	25	15–25	15	27–28	25
1–12	32	3–10	42	8–10	65	11–26	40	15–28	21	27–29	60
1–13	21	3–11	40	8–11	66.5	11–28	40	16–18	14.5	27–30	50
1–14	9	3–12	35	8–15	45	12–14	22	16–28	16	27–37	11
1–18	10	3–18	14	8–23	30	12–16	14	17–38	14	28–30	35
1–20	15	3–19	8	8–25	60	12–18	24	18–20	7	28–33	110
1–21	20	4–6	7	8–26	10	12–19	35	18–37	10	28–37	14
1–37	25	4–19	58	8–28	65	12–20	28	19–23	16	29–34	120

Table 20 continued

Corr	Length (km)	Corr	Length (km)	Corr	Length (km)	Corr	Length (km)	Corr	Length (km)	Corr	Length (km)
2–4	65	4–21	65	9–10	45	12–25	40	19–26	24	29–35	140
2–5	75	4–24	70	9–11	47	12–28	32	19–38	18	30–31	28
2–6	7	5–13	80	9–12	57	12–37	31	20–21	9	30–33	123
2–8	105	5–19	30	9–13	70	12–39	20	21–26	17	30–35	147
2–9	65	5–21	40	9–16	55	13–19	35	22–26	7	31–33	150
2–10	55	5–24	45	9–25	41	13–20	18	22–28	16	31–35	180
2–12	35	6–11	65	9–26	66	13–28	22	23–27	6	31–37	20
2–13	24	6–12	45	9–28	47	13–37	21	24–26	14	36–39	70

Table 21 Impedance, rating data ($S_b = 100$ MVA) and construction costs (Haddadian et al. 2011)

Voltage (kV)	Type	Number of bundled conductors	Rating (P.U.)	Resistance (P.U./km) ×10e−4	Reactance (P.U./km) ×10e−4	Susceptance (P.U./km) ×10e−4	Constant cost ($)×10e3	Variable cost ($)×10e3
230	CANARY	1	4	1.22	3.85	19	500	42
		2	8	0.61	2.84	24	500	43
	CARDINAL	1	4.5	1.16	3.85	19	500	45
		2	8.5	0.58	2.82	24.5	500	46
	Cable	–	3.45	1	16	3200	200	60
400	CERLEW	1	7.5	0.35	1.24	58	1600	85
		2	15	0.175	0.97	74	1600	86.5
		3	25	0.115	0.86	83	1600	87

Appendix: Capacity Outage Probability Calculation

Several indices can be calculated in transmission systems in order to asses the operation reliability. Hereby, the capacity outage probability for the RECT system is presented in Table 22, enabling the calculation of the main reliability criteria (e.g., loss of load probability (LOLP) and loss of load expectation (LOLE)) in further studies. Table 22 includes the capacity outage probabilities (COP) in the range of 0–100 MW.

Table 22 Capacity outage probability table (0–100 MW)

Cap. out (MW)	Cap. in (MW)	Ind. prob.	Cum. prob.	Cap. out (MW)	Cap. in (MW)	Ind. prob.	Cum. prob.
0	14,078.2	1.01E−05	1.0000000000	79.7 = 32 + 23.7 + 24	13,998.5	5.86E−06	0.9992957224
12.5	14,065.7	1.50E−06	0.9999899350	80 = 2 × 24 + 32	13,998.2	9.97E−07	0.9992898640
23.7	14,054.5	3.30E−05	0.9999884315	80.7 = 2 × 12.5 + 23.7 + 32	13,997.5	7.35E−07	0.9992888668
24	14,054.2	3.17E−06	0.9999554465	81 = 2 × 12.5 + 32 + 24	13,997.2	7.06E−08	0.9992881319
25	14,053.2	1.03E−05	0.9999451385	82 = 2 × 25 + 32	13,996.2	1.12E−05	0.9992880612
25 = 2 × 12.5	14,053.2	8.42E−08	0.9999348305	82 = 4 × 12.5 + 32	13,996.2	5.21E−11	0.9992768182
32	14,046.2	3.30E−05	0.9999347463	82.5	13,995.7	2.63E−06	0.9992768182
36.2 = 12.5 + 23.7	14,042	1.61E−05	0.9999017613	83.6 = 3 × 23.7 + 12.5	13,994.6	6.20E−06	0.9992741925
36.5 = 12.5 + 24	14,041.7	4.74E−07	0.9998856143	83.9 = 12.5 + 2 × 23.7 + 24	13,994.3	2.38E−06	0.9992679915
37.5 = 3 × 12.5	14,040.7	2.10E−09	0.9998851407	84.2 = 12.5 + 23.7 + 2 × 24	13,994	9.94E−07	0.9992656074
37.5 = 12.5 + 25	14,040.7	1.54E−06	0.9998851386	84.5 = 3 × 24 + 12.5	13,993.7	2.94E−09	0.9992646132
38.5	14,039.7	2.34E−06	0.9998835989	84.9 = 12.5 + 2 × 23.7 + 25	13,993.3	7.75E−06	0.9992646103
44.5 = 12.5 + 32	14,033.7	4.00E−06	0.9998812526	84.9 = 2 × 23.7 + 3 × 12.5	13,993.3	1.06E−08	0.9992568591
47.4 = 2 × 23.7	14,030.8	5.07E−05	0.9998772529	85	13,993.2	5.22E−07	0.9992568486
47.7 = 23.7 + 24	14,030.5	1.04E−05	0.9998265839	85.2 = 3 × 12.5 + 23.7 + 24	13,993	2.16E−09	0.9992563264
48 = 2 × 24	14,030.2	3.75E−07	0.9998161939	85.5 = 2 × 24 + 3 × 12.5	13,992.7	6.70E−11	0.9992563242
48.7 = 23.7 + 25	14,029.5	3.38E−05	0.9998158561	85.5 = 12.5 + 25 + 2 × 24	13,992.7	5.73E−08	0.9992563242
48.7 = 2 × 12.5 + 23.7	14,029.5	2.76E−07	0.9997820771	85.9 = 2 × 23.7 + 38.5	13,992.3	1.18E−05	0.9992562669
49 = 24 + 25	14,029.2	3.25E−06	0.9997818011	86.2 = 38.5 + 23.7 + 24	13,992	2.42E−06	0.9992444729
49 = 2 × 12.5 + 24	14,029.2	2.65E−08	0.9997785542	86.2 = 12.5 + 23.7 + 2 × 25	13,992	1.42E−06	0.9992420545
50 = 4 × 12.5	14,028.2	1.96E−11	0.9997785277	86.2 = 3 × 12.5 + 23.7 + 25	13,992	7.04E−09	0.9992406306
50 = 2 × 25	14,028.2	4.22E−06	0.9997785277	86.5 = 2 × 24 + 38.5	13,991.7	8.72E−08	0.9992406236
50 = 2 × 12.5 + 25	14,028.2	8.63E−08	0.9997743053	86.5 = 12.5 + 2 × 25 + 24	13,991.7	1.99E−07	0.9992405364
51 = 12.5 + 38.5	14,027.2	3.50E−07	0.9997742191	86.5 = 3 × 12.5 + 25 + 24	13,991.7	6.76E−10	0.9992403377
55.7 = 23.7 + 32	14,022.5	8.78E−05	0.9997738692	87.2 = 2 × 12.5 + 23.7 + 38.5	13,991	6.42E−08	0.9992403370
56 = 24 + 32	14,022.2	8.44E−06	0.9996860432	87.5 = 2 × 25 + 3 × 12.5	13,990.7	8.80E−10	0.9992402728
57 = 25 + 32	14,021.2	2.74E−05	0.9996776014	87.5 = 3 × 25 + 12.5	13,990.7	1.29E−07	0.9992402719
57 = 2 × 12.5 + 32	14,021.2	2.24E−07	0.9996501554	87.5 = 2 × 12.5 + 38.5 + 24	13,990.7	6.17E−09	0.9992401427
59.9 = 12.5 + 2 × 23.7	14,018.3	7.57E−06	0.9996499312	87.7 = 2 × 32 + 23.7	13,990.5	1.08E−04	0.9992401365
60.2 = 12.5 + 23.7 + 24	14,018	1.55E−06	0.9996423624	88 = 2 × 32 + 24	13,990.2	1.04E−05	0.9991322065
60.5 = 12.5 + 2 × 24	14,017.7	5.59E−08	0.9996408104	88.5 = 2 × 25 + 38.5	13,989.7	9.83E−07	0.9991218325
61.2 = 3 × 12.5 + 23.7	14,017	6.87E−09	0.9996407545	89 = 2 × 32 + 25	13,989.2	3.37E−05	0.9991208497
61.2 = 12.5 + 23.7 + 25	14,017	5.05E−06	0.9996407476	89 = 2 × 12.5 + 2 × 32	13,989.2	2.76E−07	0.9990871207
61.5 = 3 × 12.5 + 24	14,016.7	6.60E−10	0.9996357017	89.5 = 2 × 38.5 + 12.5	13,988.7	2.72E−08	0.9990868451
61.5 = 12.5 + 24 + 25	14,016.7	4.85E−07	0.9996357010	91.9 = 12.5 + 2 × 23.7 + 32	13,986.3	2.02E−05	0.9990868180
62.2 = 23.7 + 38.5	14,016	7.68E−06	0.9996352160	92.5 = 12.5 + 32 + 2 × 24	13,985.7	1.49E−07	0.9990666650
62.5 = 24 + 38.5	14,015.7	7.38E−07	0.9996275386	93.2 = 3 × 12.5 + 23.7 + 32	13,985	1.83E−08	0.9990665160
62.5 = 12.5 + 2 × 25	14,015.7	6.31E−07	0.9996268007	93.5 = 3 × 12.5 + 32 + 24	13,984.7	1.76E−09	0.9990664977
62.5 = 3 × 12.5 + 25	14015.7	2.15E−09	0.9996261700	94.8 = 4 × 23.7	13983.4	2.76E−05	0.9990664960
63.5 = 25 + 38.5	14,014.7	2.40E−06	0.9996261679	95 = 12.5 + 82.5	13,983.2	3.92E−07	0.9990388630
63.5 = 2 × 12.5 + 38.5	14,014.7	6.53E−09	0.9996237687	95.1 = 3 × 23.7 + 24	13,983.1	1.31E−05	0.9990384708
64 = 2 × 32	14,014.2	3.29E−05	0.9996237622	95.4 = 2 × 23.7 + 2 × 24	13,982.8	1.89E−06	0.9990253948
68.2 = 12.5 + 23.7 + 32	14,010	1.31E−05	0.9995908272	95.7 = 3 × 24 + 23.7	13,982.5	6.44E−08	0.9990235095
68.5 = 12.5 + 24 + 32	14,009.7	1.26E−06	0.9995777082	96 = 4 × 24	13,982.2	3.87E−10	0.9990234451
69.5 = 3 × 12.5 + 32	14,008.7	5.88E−07	0.9995764472	96 = 3 × 32	13,982.2	2.47E−05	0.9990234447
70.5 = 32 + 38.5	14,007.7	6.24E−06	0.9995758593	96.1 = 2 × 12.5 + 3 × 23.7	13,982.1	3.47E−07	0.9989987107

Table 22 continued

Cap. out (MW)	Cap. in (MW)	Ind. prob.	Cum. prob.	Cap. out (MW)	Cap. in (MW)	Ind. prob.	Cum. prob.
$71.1 = 3 \times 23.7$	14,007.1	4.15E−05	0.9995696214	$96.1 = 3 \times 23.7 + 25$	13,982.1	4.25E−05	0.9989983633
$71.4 = 2 \times 23.7 + 24$	14,006.8	1.60E−05	0.9995281094	$96.4 = 25 + 2 \times 23.7 + 24$	13,981.8	1.63E−05	0.9989558513
$71.7 = 23.7 + 2 \times 24$	14,006.5	1.23E−06	0.9995121494	$96.4 = 2 \times 12.5 + 2 \times 23.7 + 24$	13,981.8	1.47E−08	0.9989395063
$72 = 3 \times 24$	14,006.2	1.97E−08	0.9995109221	$96.7 = 25 + 23.7 + 2 \times 24$	13,981.5	1.26E−06	0.9989394916
$72.4 = 2 \times 23.7 + 25$	14,005.8	5.19E−05	0.9995109024	$97 = 2 \times 12.5 + 3 \times 24$	13,981.2	1.65E−10	0.9989382347
$72.7 = 23.7 + 24 + 25$	14,005.5	1.06E−05	0.9994590124	$97 = 3 \times 24 + 25$	13,981.2	2.01E−08	0.9989382345
$72.7 = 2 \times 12.5 + 23.7 + 24$	14,005.5	8.69E−08	0.9994483724	$97.4 = 2 \times 23.7 + 4 \times 12.5$	13,980.8	9.85E−11	0.9989382144
$73 = 2 \times 24 + 25$	14,005.2	3.84E−07	0.9994482855	$97.4 = 2 \times 23.7 + 2 \times 25$	13,980.8	2.13E−05	0.9989382144
$73 = 2 \times 12.5 + 2 \times 24$	14,005.2	3.13E−09	0.9994479020	$97.4 = 2 \times 12.5 + 2 \times 23.7 + 25$	13,980.8	4.34E−07	0.9988947944
$73.7 = 23.7 + 2 \times 25$	14,004.5	9.53E−06	0.9994478989	$97.5 = 12.5 + 85$	13,980.7	7.80E−08	0.9988943602
$73.7 = 4 \times 12.5 + 23.7$	14,004.5	6.42E−11	0.9994383664	$97.7 = 2 \times 25 + 23.7 + 24$	13,980.5	4.36E−06	0.9988942822
$73.7 = 2 \times 12.5 + 23.7 + 25$	14,004.5	2.63E−07	0.9994383664	$98 = 2 \times 24 + 4 \times 12.5$	13,980.2	7.28E−13	0.9988899235
$74 = 24 + 2 \times 25$	14,004.2	1.33E−06	0.9994381037	$98 = 2 \times 24 + 2 \times 25$	13,980.2	1.57E−07	0.9988899235
$74 = 4 \times 12.5 + 24$	14,004.2	6.17E−12	0.9994367737	$98.4 = 12.5 + 2 \times 23.7 + 38.5$	13,979.8	1.76E−06	0.9988897664
$74 = 2 \times 12.5 + 24 + 25$	14,004.2	2.72E−08	0.9994367737	$98.7 = 3 \times 25 + 23.7$	13,979.5	2.83E−06	0.9988880047
$74.7 = 12.5 + 23.7 + 38.5$	14,003.5	1.49E−09	0.9994367456	$99 = 3 \times 25 + 24$	13,979.2	2.72E−07	0.9988851705
$75 = 3 \times 25$	14,003.2	8.65E−07	0.9994367450	$99 = 12.5 + 38.5 + 2 \times 24$	13,979.2	1.30E−08	0.9988848981
$75 = 2 \times 12.5 + 2 \times 25$	14,003.2	3.53E−08	0.9994358802	$99 = 2 \times 12.5 + 2 \times 25 + 24$	13,979.2	1.11E−08	0.9988848851
$75 = 4 \times 12.5 + 25$	14,003.2	1.60E−11	0.9994358449	$99.7 = 3 \times 12.5 + 23.7 + 38.5$	13,978.5	1.60E−09	0.9988848740
$75 = 12.5 + 24 + 38.5$	14,003.2	1.10E−07	0.9994358449	100	13,978.2	1.28E−06	0.9988848724
$76 = 3 \times 12.5 + 38.5$	14,002.2	4.88E−10	0.9994357347	$100 = 4 \times 25$	13,978.2	8.86E−08	0.9988835875
$76.5 = 12.5 + 2 \times 32$	14,001.7	4.92E−06	0.9994357342	$100 = 2 \times 12.5 + 3 \times 25$	13,978.2	7.24E−09	0.9988834989
$77 = 2 \times 38.5$	14,001.2	1.82E−07	0.9994308142	$100 = 2 \times 25 + 4 \times 12.5$	13,978.2	8.21E−12	0.9988834917
$79.4 = 2 \times 23.7 + 32$	13,998.8	1.35E−04	0.9994306324	$100 = 3 \times 12.5 + 38.5 + 24$	13,978.2	1.54E−10	0.9988834917

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