Test Cases for Capacity Expansion Planning with Unit Commitment

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***Abstract*—This paper updates and presents six test cases; 6 bus, 6bus ww, 14 bus, 15 bus, 21 bus and 24 bus, for generation, transmission and storage expansion planning problems. The data set is consisted of cost and technical parameters for unit commitment formulation, network parameters for DC power flow and hourly chronological load and renewable generation profiles for a period of one year.**

Nomenclature

Bus	Bus number
Tindex	Technology Index
IntI	Initial existing status
C^I	Investment cost M$/MW
C^{AI}	Annualized cost (M$)
C^M	Fixed OM cost (M$/MW/yr)
C^V	Variable OM cost ($/MWh)
LS	Life span (yr)
γ	Discount rate (%)
	Nodes
Type	Bus Type
Bkv	Base kv
Lzone	Load Zone
LF	Load Factor
SF	Scaling factor
	Thermal Unitst
Pmax/Pmin	Maximum and minimum generation (MW)
IntS	Initial on off status (+ ON, - OFF)
IntP	Initial generation (MW)
MinU/MinD	Minimum up and down times (hr)
RU/RD	Ramp up and down limits (MW)
SU/SD	Start up and shut down limits (MW)
HR	Heat rate (MMBTU/MWh)
C^F	Fuel cost ($/MMBTU)
C^G	Generation cost ($/MWh)
C^{SU}	Star up cost ($/startup)
C^C	Commitment cost ($/hr)
	Transmission Lines
From/To	Connecting buses
Fmax/Fmin	Maximum and Minimum Flow (MW)
X	Reactance (p.u.)
	Storage Units
Emax	Maximum Capacity (MWh)
Char	Maximum charging limit (MW)
Dischar	Maximum discharging limit (MW)
IntE	Initial storage level (MWh)
	Renewable Units
Rmax	Maximum available generation (MW)
Rzone	Renewable zone

I. Introduction

With integration of large scale wind and solar farms, planning for operational flexibility along with generation and transmission capacities, has become an important aspect to ensure reliability of a system [1]. While there are multiple methods to attain flexibility, most common approaches can be listed as flexible generators such as gas units and energy storage systems (ESS) such as large scale battery or pumped hydro, as they are capable of responding instantly to rapid variations in renewable generation, to avoid load or renewable curtailment [2].

To accurately represent operational flexibility in planning problems, the embedded operational model must be the unit commitment formulation [3]–[5]. As unit commitment takes temporal variations in load ad renewable generation into account, technical limitations such as start up cost, ramping limits, minimum up and down times, charging and discharging limits can be modelled with great precision.

However, consideration of unit commitment in planning context require a comprehensive set of input data with detailed technical and cost parameters. While many test cases exist for operational problems such as economic dispatch, DC and AC power flow [6], [7] majority do not contain input data desired for unit commitment model or capacity expansion planning. Due to this unavailability, proposed algorithms were often evaluated using real systems that are not publicly accessible making benchmarking a repetitive costly process. Therefore, the aim of this work is to upgrade existing test cases collected from multiple sources so that they are readily available for algorithm testing. In this paper, we update six existing test cases incorporating data for generation, transmission and storage expansion planning, including cost and technical parameters for unit commitment and DC formulation, hourly load and renewable generation profiles for a period of one year.

II. System Description

This section summarizes the upgrading process conducted to generate test cases for capacity expansion planning with unit commitment. In all test cases, the obtained data serve as the existing system, while candidate units were assigned to existing buses ensuring a range of technologies are available to invest. The complete set of data can be viewed at [8].

A. Bus Data

For each bus, bus type, Base kV, load distribution factor (LF), load zone and scaling factors (SF) are provided (e.g.

Table IV). For the bus type, Matpower case format was followed [6] where 1 indicates PQ bus, 2 refers to PV bus and 3 indicates reference bus. Load distribution factors (LF) were assigned based on the original load data obtained from the test cases. For buses that do not contain any load, LF and Lzone were set to zero. The scaling factors were designed to promote new generating units and transmission lines in the panning problem. In addition, a Base MVA of 100 MVA.was considered.

B. Unit Data

A technology index was assigned to each unit according to Table I.

TABLE I: Technology Index (Ti)

1	Coal	5	Solar
2	CCGT	6	Battery Storage (Li-ion)
3	OCGT	7	Transmission lines (HV AC)
4	Wind		

Thermal Units

For thermal units, cost and technical parameters that are necessary for the unit commitment model are provided (e.g. Table V). The technical parameters and cost parameters are based on Table II [4] and Table III respectively.

TABLE II: Technical Parameters

Ti	Pmin p.u	Ramprate p.u	MinU hr	MinD hr
1	0.5	0.3	24	12
2	0.3	0.5	6	12
3	0.25	1	1	1

Renewable Units

A renewable zone was assigned to all renewable units (e.g. Table VII). Wind and solar profiles that determines the generation output of each unit are based on these zones. Note that these zones are different to load zones mentioned above and same zone number does not imply that the units and loads are co-located.

Transmission Lines

For transmission lines, information required for DC power flow calculations are provided (e.g. Table VI). The candidate lines were assigned to either increase the capacity in existing lines or install completely new lines changing the network topology.

Battery Storage battery

All battery units were allocated to regions that have great potential for renewable energy-based generation (e.g. Table VIII). The technical parameters provided are for simple storage models, hence do not include any information regarding efficiency. It is also assumed that, each unit is initially charged roughly up to 60-80% of its total capacity, before commissioning.

C. Cost Data

The cost parameters for different technologies obtained from [4], [9] are summarized in Table III. Note that investment cost C^I shown here is the total cost of installation. Annualized investment cost was calculated using Eq (1). Total annual cost C^{AI} provided in test cases are the sum of annualized capital cost and fixed operational and maintenance cost for a year C^M. In addition, total generation cost C^G is considered as the sum of fuel cost C^F and variable OM cost C^V.

TABLE III: Cost Parameters

Ti	C^I	LS	γ	HR	C^F	C^V	C^M	C^{SU+}	C^G
1	1.52	30	10	8	2.89	7.33	0.043	54.11	30.45
2	1.28	30	10	7.34	5.78	4.73	0.025	16.23	47.15
3	0.77	30	10	14.31	5.78	13.4	0.017	28.14	96.12
4	1.50	25	10	NA	NA	NA	0.060	NA	0
5	0.83	25	10	NA	NA	NA	0.015	NA	0
6	1.00	15	10	NA	NA	NA	0.012	NA	0
7	1100 *	50	7	NA	NA	NA	NA	NA	NA

* The provided value is in $/MW/km.
+ The provided value is in $/MW/startup.

$$C^{ACap} = \frac{\gamma \, C^{Cap}}{1 - (1+\gamma)^{-\mathrm{LS}}} \tag{1}$$

D. Demand, Solar and Wind Profiles

Hourly load and renewable generation profiles obtained from Australian Energy Market Operator (*aemo.com.au*) for a period of one year are provided. For load profiles appropriate scaling factors were applied and for renewable generation profiles hourly capacity factors are presented. Due to enormous amount of data, these profiles are not shown in this document and can be found at [8].

III. Test Cases

This section provides the details of the six test cases that were updated; 6 bus, 6 bus ww, 14 bus, 15 bus, 21 bus and 24 bus, where the obtained data was considered as the existing network. The technical parameters of the existing units were extended for the unit commitment problem, and candidate generators, transmission lines and storage data was added to update the test case for capacity expansion planning problems. Existing or candidate status of an unit is determined by the initial existing status "IntI" where 1 indicates "existing" and 0 otherwise. These test cases are also provided at [8] .

A. 6 Bus System

The 6-bus system was obtained from *motor.ece.iit.edu*.

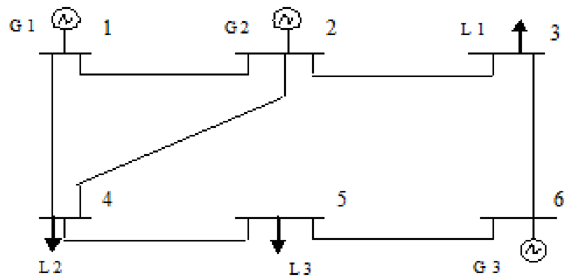

Fig. 1: 6 Bus System

TABLE IV: 6 Bus Nodes

Bus	Type	BkV	LF	Lzone	SF
1	3	230	0	0	0
2	2	230	0	0	0
3	2	230	1	1	0.0225
4	1	230	1	2	0.105
5	1	230	1	3	0.105
6	1	230	0	0	0

TABLE VI: 6 Bus Transmission Lines

Line	From	To	X	Fmax	Fmin	IntI	C^{AI}
1	1	2	0.17	200	-200	1	0
2	2	3	0.037	110	-110	1	0
3	1	4	0.258	100	-100	1	0
4	2	4	0.197	100	-100	1	0
5	4	5	0.037	100	-100	1	0
6	5	6	0.14	100	-100	1	0
7	3	6	0.018	100	-100	1	0
8	1	5	0.258	100	-100	0	0.39
9	4	5	0.037	100	-100	0	0.24
10	5	6	0.14	100	-100	0	0.56

TABLE VII: 6 Bus Renewable Generators

Gen	Bus	Ti	Rmax	Rzone	IntI	C^{AI}
1	4	4	70	1	0	15.77
2	5	4	50	1	0	11.26
3	6	5	115	3	0	12.24
4	5	5	100	3	0	10.64

TABLE VIII: 6 Bus Storage Units

ESS	Bus	Emax	Char	Dischar	IntE	IntI	C^{AI}
1	4	50	25	35	24.5	0	5.02
2	4	130	80	100	70.0	0	14.35
3	5	34	20	28	19.6	0	4.02

B. 6 Bus ww System

The 6 bus ww is based on the matpower test case [6] “6busww”. The original version can be found at [10].

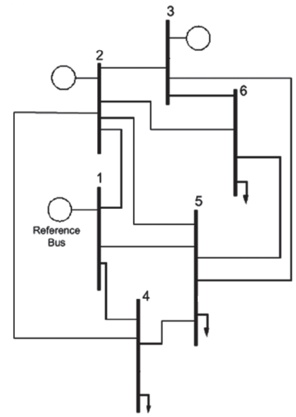

Fig. 2: 6 Bus ww System [11]

TABLE IX: 6 Bus ww Nodes

Bus	Type	BkV	LF	Lzone	SF
1	3	230	0	0	0
2	2	230	0	0	0
3	2	230	0	0	0
4	1	230	0.3	1	0.08
5	1	230	0.3	1	0.08
6	1	230	0.4	1	0.08

TABLE XI: 6 Bus ww Transmission Lines

Line	From	To	X	Fmax	Fmin	IntI	C^{AI}
1	1	2	0.2	40	-40	1	0
2	1	4	0.2	60	-60	1	0
3	1	5	0.3	40	-40	1	0
4	2	3	0.25	40	-40	1	0
5	2	4	0.1	60	-60	1	0
6	2	5	0.3	30	-30	1	0
7	2	6	0.2	90	-90	1	0
8	3	5	0.26	70	-70	1	0
9	3	6	0.1	80	-80	1	0
10	4	5	0.4	20	-20	1	0
11	5	6	0.3	40	-40	1	0
12	1	5	0.258	80	-80	0	0.32
13	4	5	0.037	70	-70	0	0.17
14	5	6	0.14	100	-100	0	0.56

TABLE XII: 6 Bus ww Renewable Generators

Gen	Bus	Ti	Rmax	Rzone	IntI	C^{AI}
1	4	4	70	1	0	15.77
2	5	4	50	1	0	11.26
3	6	5	35	3	0	3.73
4	5	5	80	3	0	8.52

TABLE XIII: 6 Bus ww Storage Units

ESS	Bus	Emax	Char	Dischar	IntE	IntI	C^{AI}
1	4	50	25	25	35	0	3.59
2	5	34	20	20	28	0	2.87

C. 14 Bus System

The 14 bus system is based on the IEEE 14 bus case which was obtained from matpower test cases [6].

TABLE V: 6 Bus Thermal Generators

Gen	Bus	Ti	Pmax	Pmin	IntS	IntP	MinU	MinD	RU	RD	SU	SD	IntI	C^{AI}	C^{SU}	C^{G}	C^{C}
1	1	1	220	110	24	160	24	12	66	66	110	110	1	0	11904	30	0
2	2	2	100	30	6	50	6	12	50	50	50	50	1	0	1623	47	0
3	6	3	20	5	1	20	1	1	20	20	20	20	1	0	562	96	0
4	1	1	100	50	-12	0	24	12	30	30	50	50	0	20.48	5411	30	0
5	2	2	100	30	-12	0	6	12	50	50	50	50	0	16.11	1623	47	0
6	6	2	50	15	-12	0	6	12	25	25	25	25	0	8.05	811	47	0
7	5	3	50	10	-1	0	1	1	50	50	50	50	0	4.93	1407	96	0

TABLE X: 6 Bus ww Thermal Generators

Gen	Bus	Ti	Pmax	Pmin	IntS	IntP	MinU	MinD	RU	RD	SU	SD	IntI	C^{AI}	C^{SU}	C^{G}	C^{C}
1	1	1	200	100	24	140	24	12	60	60	100	100	1	0	10822	30.45	0
2	2	2	150	45	6	75	6	12	75	75	75	75	1	0	2435	47.16	0
3	3	3	180	45	1	180	1	1	180	180	180	180	1	0	5065	96.12	0
4	1	1	100	50	-12	0	24	12	30	30	50	50	0	20.48	5411	30.45	0
5	2	2	100	30	-12	0	6	12	50	50	50	50	0	16.11	1623	47.16	0
6	6	2	50	15	-12	0	6	12	25	25	25	25	0	8.05	812	47.16	0
7	5	3	50	10	-1	0	1	1	50	50	50	50	0	4.93	1407	96.12	0

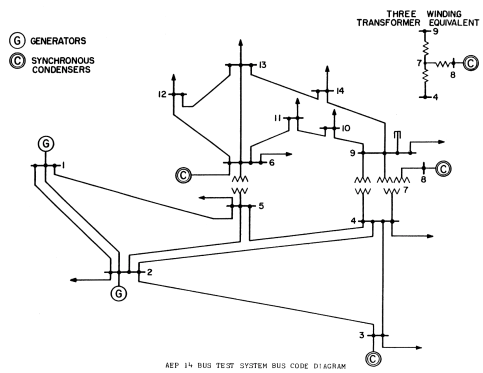

Fig. 3: IEEE 14 Bus System [11]

TABLE XIV: 14 Bus Nodes

Bus	Type	BkV	LF	Lzone	SF
1	3	230	0	0	0
2	2	230	0.0838	1	0.1563
3	2	230	0.3637	1	0.1563
4	1	230	0.1846	1	0.1563
5	1	230	0.0293	1	0.1563
6	2	230	0.0432	1	0.1563
7	1	230	0	0	0
8	2	230	0	0	0
9	1	230	0.1139	1	0.1563
10	1	230	0.0347	1	0.1563
11	1	230	0.0135	1	0.1563
12	1	230	0.0235	1	0.1563
13	1	230	0.0521	1	0.1563
14	1	230	0.0575	1	0.1563

TABLE XV: 14 Bus Renewable Generators

Gen	Bus	Ti	Rmax	Rzone	IntI	C^{AI}
1	6	4	120	1	0	27.03
2	12	4	80	1	0	18.02
3	7	4	30	1	0	6.76
4	9	5	110	3	0	11.71
5	14	5	90	3	0	9.58
6	3	4	40	3	0	4.26

TABLE XVI: 14 Bus Transmission Lines

Line	From	To	X	Fmax	Fmin	IntI	C^{AI}
1	1	2	0.05917	100	-100	1	0
2	1	5	0.22304	100	-100	1	0
3	2	3	0.19797	100	-100	1	0
4	2	4	0.17632	100	-100	1	0
5	2	5	0.17388	100	-100	1	0
6	3	4	0.17103	100	-100	1	0
7	4	5	0.04211	100	-100	1	0
8	4	7	0.20912	100	-100	1	0
9	4	9	0.55618	100	-100	1	0
10	5	6	0.25202	100	-100	1	0
11	6	11	0.1989	100	-100	1	0
12	6	12	0.25581	100	-100	1	0
13	6	13	0.13027	100	-100	1	0
14	7	8	0.17615	100	-100	1	0
15	7	9	0.11001	100	-100	1	0
16	9	10	0.0845	100	-100	1	0
17	9	14	0.27038	100	-100	1	0
18	10	11	0.19207	100	-100	1	0
19	12	13	0.19988	100	-100	1	0
20	13	14	0.34802	100	-100	1	0
21	1	2	0.05917	100	-100	0	0.40
22	2	3	0.19797	100	-100	0	0.24
23	1	3	0.34802	150	-150	0	1.08
24	10	9	0.19207	70	-70	0	0.22
25	10	14	0.27038	150	-150	0	0.83
26	6	8	0.04211	90	-90	0	0.14
27	8	9	0.19797	100	-100	0	0.28

TABLE XVII: 14 Bus Storage Units

ESS	Bus	Emax	Char	Dischar	IntE	IntI	C^{AI}
1	2	200	120	170	120	0	24.39
2	14	350	270	300	210	0	43.04
3	6	120	80	100	70	0	14.35
4	7	200	120	170	120	0	24.39

D. 15 Bus System

The 15 bus system represents a section of the IEEE 118 bus system obtained from *motor.ece.iit.edu*. More precisely it represents the buses 20 - 32,114 and 115.

TABLE XVIII: 14 Bus Thermal Generators

Gen	Bus	Ti	Pmax	Pmin	IntS	IntP	MinU	MinD	RU	RD	SU	SD	IntI	C^{AI}	C^{SU}	C^{G}	C^{C}
1	1	1	330	165	24	231	24	12	99	99	165	165	1	0	17856.3	30.45	0
2	2	1	140	70	24	98	24	12	42	42	70	70	1	0	7575.4	30.45	0
3	3	2	100	30	6	50	6	12	50	50	50	50	1	0	1623	47.1552	0
4	6	2	100	30	6	50	6	12	50	50	50	50	1	0	1623	47.1552	0
5	8	3	100	25	1	100	1	1	100	100	100	100	1	0	2814	96.1218	0
6	10	1	400	200	-24	0	24	12	120	120	200	200	0	81.92	21644	30.45	0
7	5	1	220	110	-24	0	24	12	66	66	110	110	0	45.06	11904.2	30.45	0
8	7	2	300	90	-6	0	6	12	150	150	150	150	0	48.32	4869	47.1552	0
9	13	2	200	60	-6	0	6	12	100	100	100	100	0	32.21	3246	47.1552	0
10	4	3	250	62.5	-1	0	1	1	250	250	250	250	0	24.66	7035	96.1218	0
11	11	3	120	30	-1	0	1	1	120	120	120	120	0	11.84	3376.8	96.1218	0

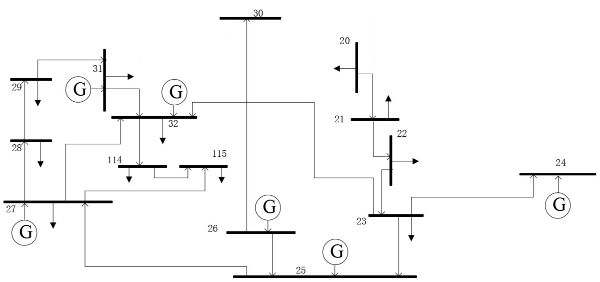

Fig. 4: 15 Bus System [11]

TABLE XIX: 15 Bus Nodes

118 Bus	Bus	Type	BkV	LF	Lzone	SF
20	1	3	138	0.063	1	0.1582
21	2	1	138	0.049	1	0.1582
22	3	1	138	0.035	1	0.1582
23	4	1	138	0.025	1	0.1582
24	5	2	138	0.000	0	0
25	6	2	138	0.000	0	0
26	7	2	345	0.000	0	0
27	8	2	138	0.218	1	0.1582
28	9	1	138	0.060	1	0.1582
29	10	1	138	0.085	1	0.1582
30	11	1	345	0.000	0	0
31	12	2	138	0.151	1	0.1582
32	13	2	138	0.208	1	0.1582
114	14	1	138	0.028	1	0.1582
115	15	1	138	0.077	1	0.1582

TABLE XXII: 15 Bus Renewable Generators

Gen	Bus	Ti	Rmax	Rzone	IntI	C^{AI}
1	2	4	120	1	0	27.03
2	5	4	80	1	0	18.02
3	9	4	30	1	0	6.76
4	14	5	110	3	0	11.71
5	5	5	90	3	0	9.58
6	15	5	40	3	0	4.26

TABLE XXIII: 15 Bus Storage Units

ESS	Bus	Emax	Char	Dischar	IntE	IntI	C^{AI}
1	2	50	25	25	35	0	3.59
2	6	34	20	20	28	0	2.87
3	14	70	50	50	60	0	7.17

TABLE XXIV: 15 Bus Transmission Lines

Line	From	To	X	Fmax	Fmin	IntI	C^{AI}
1	1	2	0.0849	175	-175	1	0
2	2	3	0.097	175	-175	1	0
3	3	4	0.159	175	-175	1	0
4	4	5	0.0492	175	-175	1	0
5	4	6	0.08	500	-500	1	0
6	7	6	0.0382	500	-500	1	0
7	6	8	0.163	500	-500	1	0
8	8	9	0.0855	175	-175	1	0
9	9	10	0.0943	175	-175	1	0
10	7	11	0.086	500	-500	1	0
11	10	12	0.0331	175	-175	1	0
12	4	13	0.1153	140	-140	1	0
13	12	13	0.0985	175	-175	1	0
14	8	13	0.0755	175	-175	1	0
15	13	14	0.0612	175	-175	1	0
16	8	15	0.0741	175	-175	1	0
17	14	15	0.0104	175	-175	1	0
18	1	3	0.0849	150	-150	0	0.60
19	4	5	0.0492	100	-100	0	0.24
20	7	5	0.0382	100	-100	0	0.28
21	7	11	0.086	100	-100	0	0.72
22	8	15	0.0741	70	-70	0	0.22
23	8	13	0.0755	200	-200	0	0.32
24	4	13	0.1153	110	-110	0	0.70

E. 21 Bus System

The 21 bus system is also part of the IEEE 118 (*motor.ece.iit.edu*) bus system where the buses 1 - 19, 113 and 117 were considered.

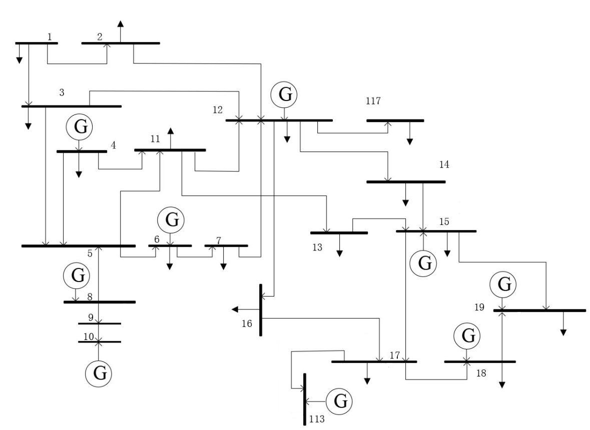

Fig. 5: 21 Bus System [11]

TABLE XX: 15 Bus Thermal Generators

Gen	Bus	Ti	Pmax	Pmin	IntS	IntP	MinU	MinD	RU	RD	SU	SD	IntI	C^{AI}	C^{SU}	C^{G}	C^{C}
1	5	2	30	9	6	15	6	12	15	15	15	15	1	0	487	47.16	0
2	6	2	300	90	6	150	6	12	150	150	150	150	1	0	4869	47.16	0
3	7	1	350	175	24	245	24	12	105	105	175	175	1	0	18939	30.45	0
4	8	1	30	15	24	21	24	12	9	9	15	15	1	0	1623	30.45	0
5	12	3	30	7.5	1	30	1	1	30	30	30	30	1	0	844	96.12	0
6	13	3	100	25	1	100	1	1	100	100	100	100	1	0	2814	96.12	0
7	8	1	300	150	24	210	24	12	90	90	150	150	0	61.44	16233	30.45	0
8	10	1	120	60	24	84	24	12	36	36	60	60	0	24.58	6493	30.45	0
9	13	2	350	105	6	175	6	12	175	175	175	175	0	56.37	5681	47.16	0
10	3	2	110	33	6	55	6	12	55	55	55	55	0	17.72	1785	47.16	0
11	9	3	250	62.5	1	250	1	1	250	250	250	250	0	24.66	7035	96.12	0
12	15	3	150	37.5	1	150	1	1	150	150	150	150	0	14.79	4221	96.12	0

TABLE XXI: 21 Bus Thermal Generators

Gen	Bus	Ti	Pmax	Pmin	IntS	IntP	MinU	MinD	RU	RD	SU	SD	IntI	C^{AI}	C^{SU}	C^{G}	C^{C}
1	4	1	30	15	24	21	24	12	9	9	15	15	1	0	1623	30.45	0
2	6	2	30	9	6	15	6	12	15	15	15	15	1	0	487	47.16	0
3	8	3	30	7.5	1	30	1	1	30	30	30	30	1	0	844	96.12	0
4	10	1	300	150	24	210	24	12	90	90	150	150	1	0	16233	30.45	0
5	12	2	300	90	6	150	6	12	150	150	150	150	1	0	4869	47.16	0
6	15	1	30	15	24	21	24	12	9	9	15	15	1	0	1623	30.45	0
7	18	3	100	25	1	100	1	1	100	100	100	100	1	0	2814	96.12	0
8	19	3	30	7.5	1	30	1	1	30	30	30	30	1	0	844	96.12	0
9	20	2	100	30	6	50	6	12	50	50	50	50	1	0	1623	47.16	0
10	4	1	300	150	24	210	24	12	90	90	150	150	0	61.44	16233	30.45	0
11	12	2	400	120	6	200	6	12	200	200	200	200	0	64.42	6492	47.16	0
12	20	3	200	50	1	200	1	1	200	200	200	200	0	19.73	5628	96.12	0
13	11	1	220	110	24	154	24	12	66	66	110	110	0	45.06	11904	30.45	0
14	16	2	170	51	6	85	6	12	85	85	85	85	0	27.38	2759	47.16	0
15	14	3	120	30	1	120	1	1	120	120	120	120	0	11.84	3377	96.12	0

TABLE XXV: 21 Bus Nodes

118 Bus	Bus	Type	BkV	LF	Lzone	SF
1	1	3	138	0.0813	1	0.2312
2	2	1	138	0.0319	1	0.2312
3	3	1	138	0.0622	1	0.2312
4	4	1	138	0.0479	1	0.2312
5	5	1	138	0.0000	0	0
6	6	1	138	0.0829	1	0.2312
7	7	1	138	0.0303	1	0.2312
8	8	1	345	0	0	0
9	9	1	345	0	0	0
10	10	1	345	0	0	0
11	11	1	138	0.1116	1	0.2312
12	12	1	138	0.0750	1	0.2312
13	13	1	138	0.0542	1	0.2312
14	14	1	138	0.0223	1	0.2312
15	15	1	138	0.1435	1	0.2312
16	16	1	138	0.0399	1	0.2312
17	17	1	138	0.0175	1	0.2312
18	18	1	138	0.0957	1	0.2312
19	19	1	138	0.0718	1	0.2312
113	20	1	138	0	0	0
117	21	1	138	0.0319	1	0.2312

TABLE XXVI: 21 Bus Storage Units

ESS	Bus	Emax	Char	Dischar	IntE	IntI	C^{AI}
1	13	34	20	20	0	0	2.87
2	15	50	25	25	0	0	3.59
3	21	30	30	30	0	0	4.30

TABLE XXVII: 21 Bus Transmission Lines

Line	From	To	X	Fmax	Fmin	IntI	C^{AI}
1	1	2	0.100	175	-175	1	0
2	1	3	0.042	175	-175	1	0
3	4	5	0.008	500	-500	1	0
4	3	5	0.108	175	-175	1	0
5	5	6	0.054	175	-175	1	0
6	6	7	0.021	175	-175	1	0
7	8	9	0.031	500	-500	1	0
8	8	5	0.027	500	-500	1	0
9	9	10	0.032	500	-500	1	0
10	4	11	0.069	175	-175	1	0
11	5	11	0.068	175	-175	1	0
12	11	12	0.020	175	-175	1	0
13	2	12	0.062	175	-175	1	0
14	3	12	0.160	175	-175	1	0
15	7	12	0.034	175	-175	1	0
16	11	13	0.073	175	-175	1	0
17	12	14	0.071	175	-175	1	0
18	13	15	0.244	175	-175	1	0
19	14	15	0.195	175	-175	1	0
20	12	16	0.083	175	-175	1	0
21	15	17	0.044	500	-500	1	0
22	16	17	0.180	175	-175	1	0
23	17	18	0.051	175	-175	1	0
24	18	19	0.049	175	-175	1	0
25	19	20	0.117	175	-175	1	0
26	15	19	0.039	175	-175	1	0
27	17	20	0.030	175	-175	1	0
28	12	21	0.140	175	-175	1	0
29	4	11	0.068	175	-175	0	0.70
30	11	12	0.020	110	-110	0	0.26
31	16	17	0.180	175	-175	0	1.12
32	17	20	0.030	175	-175	0	0.98
33	17	18	0.051	175	-175	0	0.84
34	12	21	0.140	110	-110	0	0.88

TABLE XXVIII: 21 Bus Renewable Generators

Gen	Bus	Ti	Rmax	Rzone	IntI	C^{AI}
1	7	4	70	1	0	15.77
2	4	4	40	1	0	9.01
3	17	4	50	1	0	11.26
4	1	4	35	1	0	7.88
5	14	5	80	3	0	8.52
6	13	5	45	3	0	4.79
7	11	5	20	3	0	2.13
8	21	5	35	3	0	3.73

F. 24 Bus System

The provided 24 bus system is based on the IEEE Reliability Test System - 96 [12]. The single-area version of this test case was update by C. Ordoudis *et al.* [13] for electricity market and power system operation studies. In this paper the updated version was extended to incorporate capacity expansion data.

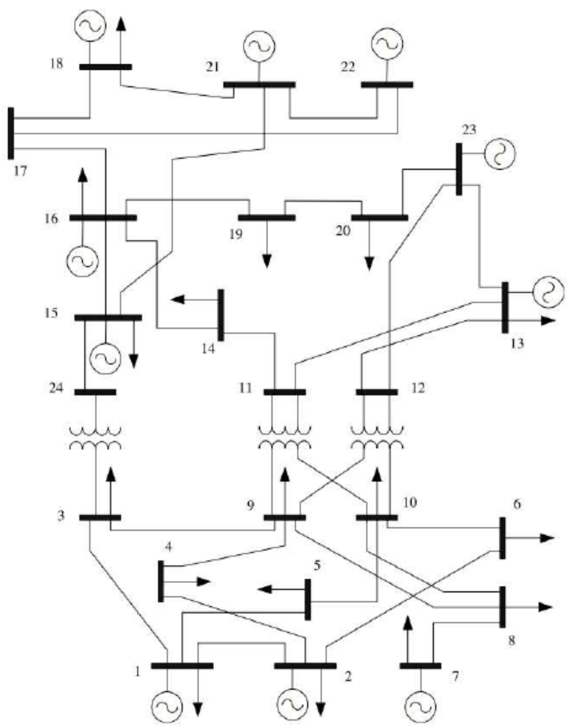

Fig. 6: IEEE RTS-24 Bus System

TABLE XXIX: 24 Bus Renewable Generators

Gen	Bus	Ti	Rmax	Rzone	IntI	C^{AI}
1	3	4	420	1	0	94.61
2	5	4	315	1	0	70.95
3	7	4	455	1	0	102.49
4	16	4	245	1	0	55.19
5	21	4	175	1	0	39.42
6	23	4	420	1	0	94.61
7	13	5	115	3	0	12.24
8	14	5	100	3	0	10.64
9	15	5	220	3	0	23.42
10	21	5	110	3	0	11.71

TABLE XXX: 24 Bus Nodes

Bus	Type	BkV	LF	Lzone	SF
1	3		0.038	1	0.75
2	1		0.034	1	0.75
3	1		0.063	1	0.75
4	1		0.026	1	0.75
5	1		0.025	1	0.75
6	1		0.048	1	0.75
7	1		0.044	1	0.75
8	1		0.06	1	0.75
9	1		0.061	1	0.75
10	1		0.068	1	0.75
11	1		0	0	0.75
12	1		0	0	0.75
13	1		0.093	1	0.75
14	1		0.068	1	0.75
15	1		0.111	1	0.75
16	1		0.035	1	0.75
17	1		0	0	0.75
18	1		0.117	1	0.75
19	1		0.064	1	0.75
20	1		0.045	1	0.75
21	1		0	0	0.75
22	1		0	0	0.75
23	1		0	0	0.75
24	1		0	0	0.75

TABLE XXXII: 24 Bus Transmission Lines

Line	From	To	X	Fmax	Fmin	IntI	C^{AI}
1	1	2	0.0146	175	-175	1	0
2	1	3	0.2253	175	-175	1	0
3	1	5	0.0907	350	-350	1	0
4	2	4	0.1356	175	-175	1	0
5	2	6	0.205	175	-175	1	0
6	3	9	0.1271	175	-175	1	0
7	3	24	0.084	400	-400	1	0
8	4	9	0.111	175	-175	1	0
9	5	10	0.094	350	-350	1	0
10	6	10	0.0642	175	-175	1	0
11	7	8	0.0652	350	-350	1	0
12	8	9	0.1762	175	-175	1	0
13	8	10	0.1762	175	-175	1	0
14	9	11	0.084	400	-400	1	0
15	9	12	0.084	400	-400	1	0
16	10	11	0.084	400	-400	1	0
17	10	12	0.084	400	-400	1	0
18	11	13	0.0488	500	-500	1	0
19	11	14	0.0426	500	-500	1	0
20	12	13	0.0488	500	-500	1	0
21	12	23	0.0985	500	-500	1	0
22	13	23	0.0884	250	-250	1	0
23	14	16	0.0594	250	-250	1	0
24	15	16	0.0172	500	-500	1	0
25	15	21	0.0249	400	-400	1	0
26	15	24	0.0529	500	-500	1	0
27	16	17	0.0263	500	-500	1	0
28	16	19	0.0234	500	-500	1	0
29	17	18	0.0143	500	-500	1	0
30	17	22	0.1069	500	-500	1	0
31	18	21	0.0132	1000	-1000	1	0
32	19	20	0.0203	1000	-1000	1	0
33	20	23	0.0112	1000	-1000	1	0
34	21	22	0.0692	500	-500	1	0
35	1	2	0.0146	175	-175	0	0.70
36	6	10	0.0642	175	-175	0	0.42
37	7	8	0.0652	350	-350	0	2.23
38	13	23	0.0884	250	-250	0	1.39
39	14	16	0.0594	250	-250	0	1.20
40	15	21	0.0249	400	-400	0	3.19

TABLE XXXI: 24 Bus Thermal Generators

Gen	Bus	Ti	Pmax	Pmin	IntS	IntP	MinU	MinD	RU	RD	SU	SD	IntI	C^{AI}	C^{SU}	C^{G}	C^{C}
1	1	2	152	45.6	6	76	6	12	76	76	76	76	1	0	2466.96	47.1552	0
2	2	3	152	38	1	152	1	1	152	152	152	152	1	0	4277.28	96.1218	0
3	7	1	350	175	24	245	24	12	105	105	175	175	1	0	18938.5	30.45	0
4	13	1	591	295.5	24	413.7	24	12	177.3	177.3	295.5	295.5	1	0	31979.01	30.45	0
5	15	3	60	15	1	60	1	1	60	60	60	60	1	0	1688.4	96.1218	0
6	15	2	155	46.5	6	77.5	6	12	77.5	77.5	77.5	77.5	1	0	2515.65	47.1552	0
7	16	3	155	38.75	1	155	1	1	155	155	155	155	1	0	4361.7	96.1218	0
8	18	1	400	200	24	280	24	12	120	120	200	200	1	0	21644	30.45	0
9	21	2	400	120	6	200	6	12	200	200	200	200	1	0	6492	47.1552	0
10	22	1	300	150	24	210	24	12	90	90	150	150	1	0	16233	30.45	0
11	23	2	310	93	6	155	6	12	155	155	155	155	1	0	5031.3	47.1552	0
12	23	1	350	175	24	245	24	12	105	105	175	175	1	0	18938.5	30.45	0
13	5	1	300	150	-12	0	24	12	90	90	150	150	0	61.4401372	16233	30.45	0
14	17	2	400	120	-12	0	6	12	200	200	200	200	0	64.42457511	6492	47.1552	0
15	10	3	200	50	-1	0	1	1	200	200	200	200	0	19.72620423	5628	96.1218	0
16	20	1	600	300	-12	0	24	12	180	180	300	300	0	122.8802744	32466	30.45	0
17	9	2	350	105	-12	0	6	12	175	175	175	175	0	56.37150322	5680.5	47.1552	0
18	24	3	240	60	-1	0	1	1	240	240	240	240	0	23.67144508	6753.6	96.1218	0

TABLE XXXIII: 24 Bus Storage Units

ESS	Bus	Emax	Char	Dischar	IntE	IntI	C^{AI}
1	13	200	150	170	120	0	24.39
2	15	350	300	300	210	0	43.04
3	21	120	80	100	70	0	14.35
4	14	200	160	180	130	0	25.83
5	20	350	300	320	225	0	45.91
6	23	400	350	370	230	0	53.09

IV. Summary

In this paper, six test cases; 6 bus, 6 bus ww, 14 bus, 15 bus, 21 bus and 24 bus were updated for capacity expansion planning problems with unit commitment. The test cases were collected from multiple sources and the obtained data was considered as the existing system. Existing thermal units were updated with unit commitment data and the candidate thermal units, renewable units, battery storage units and transmission lines were added for the planning problem. A summary of the test cases is provided in Table XXXIV

TABLE XXXIV: Summary of Test Cases

Test Case		6	6ww	14	15	21	24
Existing	Thermal	3	3	5	6	9	12
	Renewables	0	0	0	0	0	0
	Lines	7	11	20	17	28	34
	Storage	0	0	0	0	0	0
Candidate	Thermal	4	4	6	6	6	6
	Renewables	4	4	6	6	8	10
	Lines	3	3	7	7	6	6
	Storage	3	2	4	3	3	6

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References

[1] "Planning for the renewable future : Long-term modelling and tools to expand variable renewable power in emerging economies," *International Renewable Energy Agency (IRENA)*, 2017.

[2] A. van Stiphout, K. D. Vos, and G. Deconinck, "Operational flexibility provided by storage in generation expansion planning with high shares of renewables," in *2015 12th International Conference on the European Energy Market (EEM)*, pp. 1–5, May 2015.

[3] B. Palmintier and M. Webster, "Impact of unit commitment constraints on generation expansion planning with renewables," in *2011 IEEE Power and Energy Society General Meeting*, pp. 1–7, July 2011.

[4] B. Hua, R. Baldick, and J. Wang, "Representing operational flexibility in generation expansion planning through convex relaxation of unit commitment," *IEEE Transactions on Power Systems*, vol. 33, pp. 2272–2281, March 2018.

[5] Q. Xu, S. Li, and B. F. Hobbs, "Generation and storage expansion co-optimization with consideration of unit commitment," in *2018 IEEE International Conference on Probabilistic Methods Applied to Power Systems (PMAPS)*, pp. 1–6, June 2018.

[6] R. Zimmerman and C. MurilloSanchez, *MATPOWER User's Manual version 7.0b1*. Available at http://www.pserc.cornell.edu/matpower/manual.pdf.

[7] C. Coffrin, D. Gordon, and P. Scott, "Nesta, the nicta energy system test case archive," *CoRR*, vol. abs/1411.0359, 2014.

[8] S. Wijekoon, "Data Set for Capacity Expansion Planning with Unit Commitment," 5 2019. Available at https://monash.figshare.com/articles/Data_Set_for_Capacity_Expansion_Planning_with_Unit_Commitment/8131529.

[9] S. Abdurrahman and S. M. Kristensen, "Technology data for the indonesian power sector."

[10] A. J. Wood and B. F. Wollenberg, *Power Generation, Operation, and Control*. John Wiley & Sons, 2nd ed.

[11] R. D. Christie, "Power systems test case archive." Available at http://labs.ece.uw.edu/pstca/pf14/pg_tca14bus.htm.

[12] C. Grigg, P. Wong, P. Albrecht, R. Allan, M. Bhavaraju, R. Billinton, Q. Chen, C. Fong, S. Haddad, S. Kuruganty, W. Li, R. Mukerji, D. Patton, N. Rau, D. Reppen, A. Schneider, M. Shahidehpour, and C. Singh, "The ieee reliability test system-1996. a report prepared by the reliability test system task force of the application of probability methods subcommittee," *IEEE Transactions on Power Systems*, vol. 14, pp. 1010–1020, Aug 1999.

[13] C. Ordoudis, P. Pinson, G. Morales, M. Juan, and M. Zugno, "An updated version of the ieee rts 24-bus system for electricity market and power system operation studies."