Representative GB Network

September 14, 2019

Abstract

This brief report accompanies the data provided for performing power-flow and dynamic studies on the Representative GB Network. This is a reduced model, representative of the GB system. The topology and power-flow data in this report are imported from [1] and the dynamic data adapted from [2].

1 Power-flow model

1.1 Transmission nodes

For the transmission nodes, the nominal voltage and the shunt components are adapted from [2]. The shunt elements on the buses have been aggregated with the line shunt elements in the reduced parts of the GB system ('Bint') and attached to each node. Further to this, at buses 26 and 27, the interconnection shunts have been included. The updated data is listed in Table 1. The one-line diagram of the system illustrating the generation units and loads at each bus node is illustrated in Figure 1.

Table 1: Transmission nodes

Node	Location	Vnom (kV)	Shunt (MVAr)
1	Beauly	275	159
2	Peterhead	275	237.6
3	Errochty	132	84
4	Denny/Bonnybridge	275	305
5	Neilston	400	216
6	Strathaven	400	573
7	Torness	400	456.7
8	Eccles	400	14.57
9	Harker	400	397.08
10	Stella West	400	765
11	Penwortham	400	1306
12	Deeside	400	676
13	Daines	400	860.9999
14	Th. Marsh/Stockbridge	400	243
15	Thornton/Drax/Egg	400	876.5301
16	Keadby	400	346.4
17	Rattcliffe	400	561.56
18	Feckenham	400	4640.6
19	Walpole	400	564.2
20	Bramford	400	370.7
21	Pelham	400	489.29
22	Sundon/East Claydon	400	2082.4
23	Melksham	400	1737.3
24	Bramley	400	510.67
25	London	400	3513
26	Kemsley	400	1314
27	Sellindge	400	1062
28	Lovedean	400	1168.6
29	SWP	400	1806.1

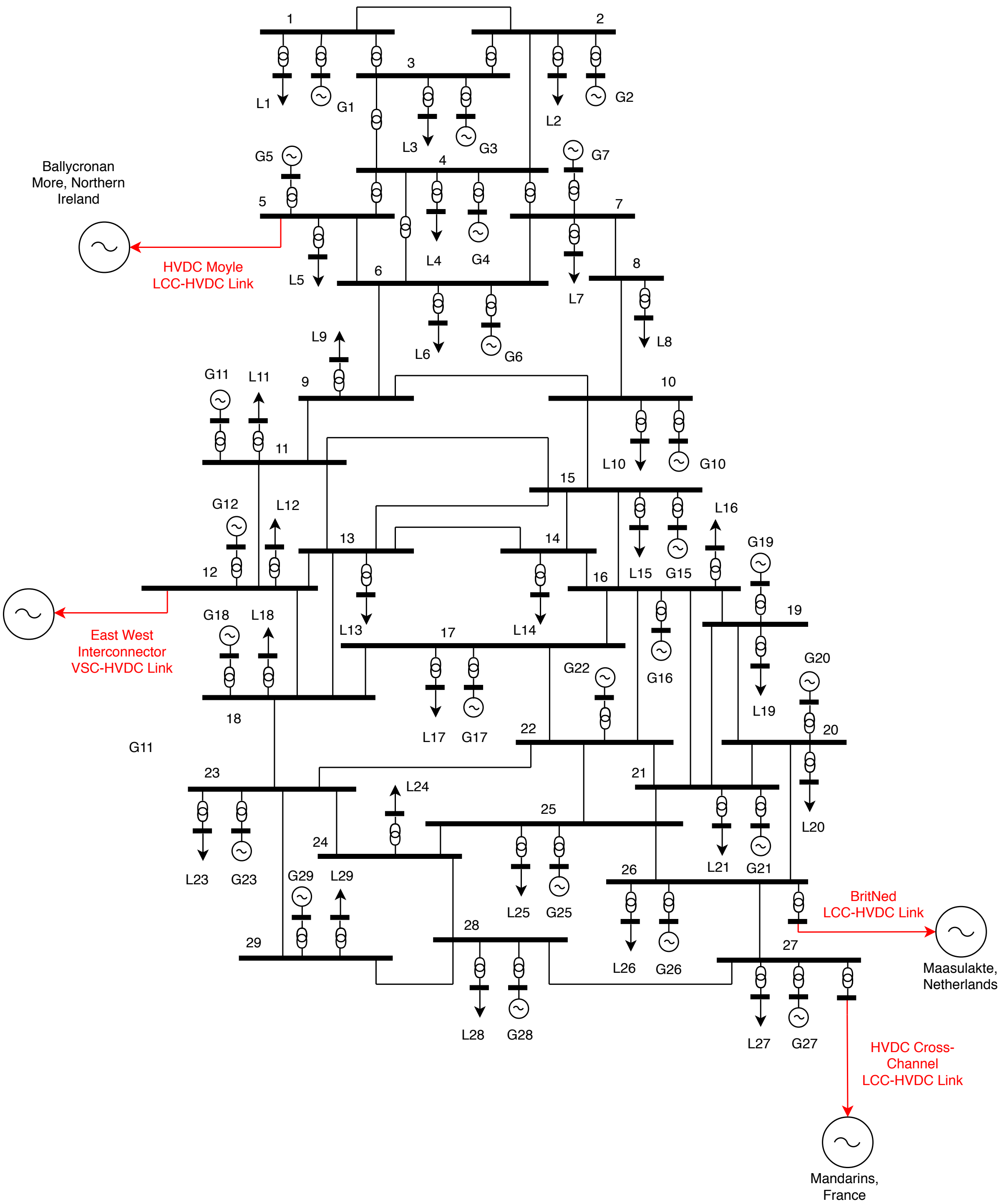

Figure 1: Representative GB Network oneline diagram

1.2 Transformer data

1.2.1 Generator and load transformers

The main alteration made to the data compared to [1] was to include step-up and step-down transformers at the generator and load buses respectively to make the system more realistic for dynamic analysis. The original data had the generators and loads directly connected to the HV nodes. Generator transformers' were included in the model in [2] but were slightly adjusted. The updated data is shown below in Table 2.

Table 2: Generator and load transformer data

Name	From Bus	To Bus	Resistance R (%)	Reactance X (%)	Susceptance B (%)	Ratio, n (%)	Snom (MVA)
G1	G1	1	0	10	0	100	1184
G2	G2	2	0	10	0	100	1800
G3	G3	3	0	10	0	100	1150
G4	G4	4	0	10	0	100	3400
G5	G5	5	0	10	0	100	1280
G6	G6	6	0	10	0	100	1300
G7	G7	7	0	10	0	100	2900
G10	G10	10	0	10	0	100	4000
G11	G11	11	0	10	0	100	6700
G12	G12	12	0	10	0	100	4800
G15	G15	15	0	10	0	100	8960
G16	G16	16	0	10	0	100	14140
G17	G17	17	0	10	0	100	2360
G18	G18	18	0	10	0	100	2550
G19	G19	19	0	10	0	100	3864
G20	G20	20	0	10	0	100	1900
G21	G21	21	0	10	0	100	875
G22	G22	22	0	10	0	100	483
G23	G23	23	0	10	0	100	9250
G25	G25	25	0	10	0	100	2750
G26	G26	26	0	10	0	100	6550
G27	G27	27	0	10	0	100	1550
G28	G28	28	0	10	0	100	1750
G29	G29	29	0	10	0	100	2400
L1-1	L1	1	0	10	0	96.5625	750
L2-2	L2	2	0	10	0	94.6875	950
L3-3	L3	3	0	10	0	95.625	900
L4-4	L4	4	0	10	0	94.6875	2250
L5-5	L5	5	0	10	0	96.5625	800
L6-6	L6	6	0	10	0	94.6875	2150
L7-7	L7	7	0	10	0	95.625	1250
L8-8	L8	8	0	10	0	96.5625	175
L9-9	L9	9	0	10	0	92.8125	325
L10-10	L10	10	0	10	0	96.5625	4000
L11-11	L11	11	0	10	0	94.6875	5500
L12-12	L12	12	0	10	0	94.6875	2300
L13-13	L13	13	0	10	0	93.75	4000
L14-14	L14	14	0	10	0	93.75	2900
L15-15	L15	15	0	10	0	94.6875	4500
L16-16	L16	16	0	10	0	91.875	5100
L17-17	L17	17	0	10	0	93.75	2000
L18-18	L18	18	0	10	0	94.6875	9000

L19-19	L19	19	0	10	0	92.8125	3750
L20-20	L20	20	0	10	0	93.75	1800
L21-21	L21	21	0	10	0	91.875	1500
L22-22	L22	22	0	10	0	92.8125	3300
L23-23	L23	23	0	10	0	94.6875	8000
L24-24	L24	24	0	10	0	93.75	2300
L25-25	L25	25	0	10	0	92.8125	15500
L26-26	L26	26	0	10	0	93.75	2800
L26IC-26	L26IC	26	0	10	0	97.5	1400
L27-27	L27	27	0	10	0	93.75	800
L27IC-27	L27IC	26	0	10	0	93.75	2800
L28-28	L28	28	0	10	0	95.625	4200
L29-29	L29	29	0	10	0	98.4375	3800

1.2.2 Transmission transformers

The transformer data in the transmission level were given in [2] and translated from PowerFactory. This data is shown below in Table 3.

Table 3: HV transformer data

Name	From Bus	To Bus	Resistance R (%)	Reactance X (%)	Susceptance B (%)	Ratio, n (%)	Phase Shift (Deg)	Snom (MVA)
1-3a	1	3	0.924	19.8	3.939	100	2	132
1-3b	1	3	0.924	19.8	3.939	100	2	132
3-4b	3	4	1.944	26.568	0.068	100	0	648
3-4a	3	4	1.944	26.568	0.679	100	0	648
3-2a	3	2	19.586	50.204	0.19	100	0	652
4-7a	4	7	2.2999	14.715	1.077	100	0	1090
4-6b	4	6	1.95	34.5	0.997	100	0	1500
4-6a	4	6	1.456	25.76	1.57	100	0	1120
4-5b	4	5	1	24	1.25	100	0	1000
4-5a	4	5	1	24	1.25	100	0	1000
4-7b	4	7	2.289	14.715	1.411	100	0	1090
12-18b	12	18	1.776	21.6	1.213	100	2	2400
12-18a	12	18	2.976	33.418	1.242	100	2	2400

1.3 Load data

The loads active and reactive powers have been kept the same as the initial data ([1]). However, due to the addition of step-up and step-down transformers, there is a change in the reactive power drawn from the transmission. This has been offset by the use of local shunt compensation to keep the transmission-level power flow in the system as close to the original ([1]) as possible.

Furthermore, the losses within the reduced parts of the GB network have been added to the active and reactive loads on the nodes. The power transferred over the interconnections has been included as loads in the data of Table 4 (see L26IC and L27IC) which are connected to their corresponding main bus nodes (26 and 27, respectively).

Table 4: Load data

Node	Vnom (kV)	Active Power Load (MW)	Reactive Power Load (MVAr)	Load Shunt (MVAr)
L1	20	490	242.5	29.9
L2	20	543	420	33.7
L3	20	599	263.4	35.8

L4	20	1327.3	923.5	82.1
L5	20	505.8	260.2	32.7
L6	20	1303.4	827.7	75.9
L7	20	753	496.9	45.3
L8	20	118.5	44.1	6.2
L9	20	134.9	192.4	11.1
L10	20	2569	1225	140.3
L11	20	3413.4	2182.7	197.7
L12	20	1209	1112	80.8
L13	20	2545	1498.5	147
L14	20	1843.5	1065.7	104
L15	20	2669	1902.4	160.3
L16	20	1691.5	3389.6	181.3
L17	20	1095.5	942.1	70.3
L18	20	5437.5	3667	322
L19	20	2066.1	1741	131.9
L20	20	1041.4	788.8	65.8
L21	20	719	848.2	56.9
L22	20	1861.8	1498.1	115.7
L23	20	4781.4	3185.8	281.7
L24	20	1423.9	894.7	83.5
L25	20	9804.7	5569.7	552.8
L26	20	1450	1426	94.7
L26IC	20	1022.3	33.4	52.7
L27	20	462.8	359.7	10.2
L27IC	20	1598	1200	91.3
L28	20	2762	1242.7	149.1
L29	20	2602	923.7	138.1

1.4 Generation data

Similarly, to the load data, the generators have also been slightly adjusted to include the transformers by the addition of shunts so that the generation matches that in the initial data. This is shown below in Table 5.

Table 5: Generation data

Node	Vnom (KV)	Active Power (MW)	Reactive Power (MVAr)	Snom (MVA)	Generation Shunt (MVAr)
G1	14.4	854	-49.2024	1184	182.18
G2	20	1264	266.9913	1800	39.16
G3	12.5	780	252.6735	1150	28.47
G4	22	2337	597.0957	3400	60.66
G5	18	882	-28.91589	1280	226.4
G6	15	871	244.8738	1300	40.06
G7	18	2047	-111.0223	2900	413.37
G10	18	2817	233.7053	4000	449.13
G11	18	4576	1189.248	6700	420.73
G12	20	3353	375.6324	4800	601.28
G15	22	6271.8	1243.344	8960	878.93
G16	22	9838	3118.91	14140	831.8
G17	22	1608	356.1637	2360	244.12
G18	22	1759	-45.34896	2550	647.23
G19	22	2614	1201.088	3864	200.67

G20	18	1254	304.4137	1900	265.18
G21	20	535	325.9548	875	0
G22	13.8	323	130.0287	483	40.97
G23	22	6180	1254.386	9250	1270.8
G25	13.8	1708	941.0302	2750	411.8
G26	20	4430	434.8855	6550	1352.77
G27	18	1032.739	416.2108	1550	42.28
G28	20	1229	248.3196	1750	155.79
G29	18	1742	-639.8749	2400	720.3

1.5 Branch data

The line data of [2] was given in p.u. format and therefore needed to be recalculated for Ω. This was translated using the equations below with a base power of 100MVA.

$$Z_{base} = \frac{V_{base}^2}{S_{base}}$$

From the base impedance's, the following can be calculated.

$$R, X(\Omega) = (Z_{base}(R, X(p.u.))$$

$$\frac{\omega C}{2}(S) = \frac{B(p.u.)}{2.Z_{base}}$$

The resulting data is presented below in Table 6.

Table 6: Branch data

Branch	From Bus	To Bus	Resistance R (ω)	Reactance X (ω)	Susceptance wC/2 (μS)	Snom (MVA)
1-2b	1	2	9.226	15.125	56.595	525
1-2a	1	2	9.226	15.125	188.033	525
2-4a	2	4	0.303	49.156	294.479	760
2-4b	2	4	0.303	49.156	366.612	760
5-6a	5	6	1.36	16.816	119.544	1390
5-6b	5	6	2.416	25.808	185.3	1390
6-9b	6	9	1.248	13.632	23.031	2100
6-9a	6	9	1.248	13.632	144.844	2100
7-8b	7	8	0.64	0.16	227.5	2180
7-8a	7	8	0.64	0.16	402.25	2500
7-6b	7	6	4.8	320	91.8438	950
7-6a	7	6	4.8	320	91.8438	950
8-10a	8	10	1.328	28	207	3070
8-10b	8	10	1.328	28	207	3070
9-11a	9	11	2.624	26.08	152.125	1390
9-11b	9	11	2.624	26.08	152.125	1390
9-10b	9	10	5.632	39.248	59.3125	855
9-10a	9	10	7.872	54.88	78.1875	775
10-15b	10	15	0.848	13.36	1679.06	4840
10-15a	10	15	0.832	10.08	332.375	4020
11-15b	11	15	1.12	67.2	122.094	2520
11-15a	11	15	1.584	67.2	179.313	2520
11-13b	11	13	0.64	8.32	78.0625	2170
11-13a	11	13	0.64	8.32	83.25	2210

11-12b	11	12	0.16	13.6	24.9375	3320
11-12a	11	12	0.16	13.6	24.9375	3320
12-13a	12	13	1.536	17.248	120.313	3100
12-13b	12	13	1.552	14.4	119.844	2400
13-18b	13	18	0.784	11.2	60.7188	2400
13-18a	13	18	1.344	11.2	242.469	2400
13-15b	13	15	2.192	36.8	207.594	1240
13-15a	13	15	2.624	36.8	34.5	955
13-14a	13	14	1.712	18.608	367.031	1040
13-14b	13	14	1.312	19.216	378.906	1040
14-16b	14	16	0.8	25.6	87.3437	2580
14-16a	14	16	8	28.8	45.8125	625
15-16b	15	16	0.528	8.32	110.437	2770
15-16a	15	16	0.256	2.752	124.75	5540
15-14b	15	14	0.304	3.552	237.25	5000
15-14a	15	14	0.288	3.552	174.156	5000
16-19b	16	19	0.896	22.56	140.5	2780
16-19a	16	19	0.896	22.56	140.5	3820
17-16b	17	16	1.6	17.152	82.8438	2150
17-16a	17	16	1.6	17.152	142.906	1890
17-22b	17	22	1.088	15.52	142.688	2100
17-22a	17	22	1.104	15.52	142.938	2100
18-17b	18	17	0.672	2.88	73.4063	3100
18-17a	18	17	0.672	2.88	73.4063	3460
18-23b	18	23	2.208	15.36	150.906	1970
18-23a	18	23	1.872	15.36	128.813	1970
20-26b	20	26	0.56	3.68	70.2813	2780
20-26a	20	26	0.56	3.68	70.2813	2780
20-19b	20	19	2.848	34.08	208.813	1590
20-19a	20	19	2.112	22.88	114.25	1590
21-16b	21	16	2.32	29.184	286.531	2780
21-16a	21	16	2.32	29.184	286.531	2780
21-25b	21	25	0.4	16	49.5625	2780
21-25a	21	25	0.4	6	49.5625	2780
21-20b	21	20	1.92	7.68	138.938	2780
21-20a	21	20	1.92	7.68	218.75	2780
21-19b	21	19	0.592	9.44	91.875	3030
21-19a	21	19	0.592	9.44	92.3438	2780
22-16b	22	16	2.848	27.52	262.594	2010
22-16a	22	16	2.848	27.52	195.938	2010
22-25b	22	25	0.592	6.56	128.063	3275
22-25a	22	25	0.544	6.56	134.063	3275
22-21b	22	21	0.304	1.776	38.5	2780
22-21a	22	21	0.768	9.76	95.0313	2780
23-29a	23	29	2.416	29.12	165.625	2010
23-24b	23	24	1.376	1.28	300.688	2780
23-24a	23	24	0.368	1.12	888.969	4400
23-22b	23	22	0.88	4.8	108.375	2780
23-22a	23	22	0.624	4.8	77.0625	2770
23-29b	23	29	2.416	29.12	165.625	2010
24-28a	24	28	1.088	11.2	74.625	2210
24-25b	24	25	1.664	14.56	91.1875	1390
24-25a	24	25	1.664	14.56	91.1875	1390

24-28b	24	28	1.088	11.2	74.625	2210
25-26b	25	26	0.32	9.12	166.25	6960
25-26a	25	26	0.32	9.12	166.25	5540
27-26b	27	26	0.32	8.048	56.1563	3100
27-26a	27	26	0.32	8.048	56.1563	3100
28-27b	28	27	0.608	11.376	93.6875	3070
28-27a	28	27	0.608	11.376	93.6875	3070
29-28b	29	28	0.816	12.736	106.25	2780
29-28a	29	28	0.816	12.736	106.25	2780

1.6 SVC data

The SVC data has been imported directly from [2] and shown in Table 7.

Table 7: SVC data

Name	Controlled Bus	Monitored Bus	Voltage Setpoint	Reactive Power Setpoint	Snom (MVA)	Max Q Nominal	Min Q Nominal
SVC2	2	2	1	3.169282	225	225	-75
SVC9	9	9	0	-142.76	334.06	334.06	-142.76
SVC18	18	18	1	21.6757	1068.69	1068.69	-358.27
SVC21	21	21	1	11.2066	341.02	341.02	-141.28
SVC22	22	22	1	12.0999	391.15	391.15	-60
SVC23	23	23	1	5.70519	240	240	0
SVC25	25	25	1	29.7217	694.06	694.06	-337.12
SVC27	27	27	1	8.24184	319.28	319.28	-283.6
SVC28	28	28	1	6.72941	341.02	341.02	-203.18
SVC29	29	29	1	0.61233	862.04	862.04	-312.56

2 Dynamic models

For the power flow solution, one generator has been connected to each node to represent the combined power from different sources. For the dynamic studies, six types of dynamic models are used:

- Combined Cycle Gas Turbine power plant (CCGT)
- Coal power plant (THERM)
- Hydro power plant (HYDR)
- Nuclear power plant (NUCL)
- DFIG Wind Turbine (WT3)
- Fully converter-based generators (CONV), e.g., WT4 or PV

For this system to be a true representative of the GB network, the dynamic models have been derived with sensible parameters for each of the above mentioned energy sources. CCGT, COAL, NUCL and HYDR models are build using synchronous machines with varied parameters. In RAMSES, all synchronous machines use the well-known 6th order model and therefore the CCGT, THERM and NUCL models are based on standard large generators and the HYDR generators parameters have been altered based on some existing generic hydro models.

Table 8: Synchronous machine parameters

Name	H X'q	D X"q	IBRATIO m	XT/RL n	Xl Ra	Xd T'do	X'd T"do	X"d T'qo	Xq T"qo
CCGT	5.500 0.500	0.000 0.300	1.850 0.000	XT 1.000	0.150 0.000	2.000 5.143	0.350 0.042	0.250 2.160	1.800 0.083
THERM	5.500 0.500	0.000 0.300	1.850 0.000	XT 1.000	0.150 0.000	2.000 5.143	0.350 0.042	0.250 2.160	1.800 0.083
NUCL	5.500 0.500	0.000 0.300	1.850 0.000	XT 1.000	0.150 0.000	2.000 5.143	0.350 0.042	0.250 2.160	1.800 0.083
HYDR	3.000 *	0.000 0.200	0.950 0.100	XT 6.026	0.150 0.000	1.100 5.000	0.250 0.050	0.200 *	0.700 0.100

For the remaining wind and converter based energy sources, injector models have been used where the models and data have been based on generic standardised WECC type 3 and type 4 models, respectively which are used for stability studies [3].

Table 9: Wind turbine parameters (WT3)

X_{eq}	H_g	H_t	D_{tg}	K_{tg}	R	ratio	p	ρ	β_0
0.8	0.962	3.395	2.344	1.387	35.25	90	4	1.225	0
β_{min}	β_{max}	$\dot{\beta}_{min}$	$\dot{\beta}_{max}$	T_p	K_{pc}	K_{ic}	K_{pp}	K_{ip}	T_{pc}
0	27	-10	10	0.3	0.5	5	150	25	0.05
K_{ptrq}	K_{itrq}	T_w	K_{Vi}	K_{Qp}	K_{Qi}	XI_{Qmin}	XI_{Qmax}	V_{min}	V_{max}
3	0.6	5	40	0.05	0.1	0.5	1.4	0.9	1.1
Q_{min}	Q_{max}	T_c	T_v	T_r	K_{pv}	K_{iv}	K_{pll}	$\dot{\theta}_{min}$	$\dot{\theta}_{max}$
-0.436	0.296	0.15	0.05	0.05	18	5	30	-0.1	0.1
T_{con}	R_{comp}	X_{comp}	ω_{min}	ω_{max}	P_{min}	P_{max}	$\dot{P}_{min}$	$\dot{P}_{max}$	mode
0.02	0	0	0.7	1.2	0.1	1.12	-0.45	0.45	2

Table 10: Converter parameters (based on WECC WT4 model)

H_t	R	ratio	poles	ρ	β_0	β_{min}	β_{max}	$\dot{\beta}_{min}$	$\dot{\beta}_{max}$
4.18	35.25	90	4	1.225	0	0	27	-10	10
T_p	K_{pc}	K_{ic}	K_{pp}	K_{ip}	T_{pc}	K_{ptrq}	K_{itrq}	T_w	K_{Vi}
0.3	3	30	150	25	0.05	0.3	0.1	5	40
K_{Qp}	K_{Qi}	V_{min}	V_{max}	I_{qhl}	I_{phl}	I_{maxtd}	pqflag	Q_{min}	Q_{max}
0.05	0.1	0.9	1.1	1.25	1.11	1.0	0	-0.436	0.296
T_c	T_v	T_r	K_{pv}	K_{iv}	K_{dbr}	E_{bst}	K_{pll}	$\dot{\theta}_{min}$	$\dot{\theta}_{max}$
0.15	0.05	0.05	18	5	10	0.2	30	-0.1	0.1
T_{con}	R_{comp}	X_{comp}	ω_{min}	ω_{max}	P_{min}	P_{max}	$\dot{P}_{min}$	$\dot{P}_{max}$	mode
0.02	0	0	0.7	1.2	0.1	1.12	-0.45	0.45	1

Further to this, all standard control such as excitation systems and governors at each node have been modelled where the IEEE ST1A excitation system has been used as this is a common standard IEEE model [4].

Table 11: ST1A Exciter Parameters

ST1A											
K_v	R_c	X_c	T_R	UEL	VI_{MIN}	VI_{MAX}	V_{UEL}	T_C	T_B	T_{C1}	T_{B1}
1.00	0.00	0.00	0.00	1.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00
K_A	T_A	VA_{MIN}	VA_{MAX}	VR_{MIN}	VR_{MAX}	K_C	K_F	T_F	K_{LR}	I_{LR}	
25.00	0.59	-9999.	9999.	0.00	3.00	0.00	0.00	1.00	0.00	0.00	

Varied governors have been implemented with adjusted parameters according to these sources. For the CCGT and coal synchronous machine models, the TGOV1 model has been used and is shown in Figure 2 [5], generic governor models are used for HYDR and the governor is set to constant speed for NUCL.

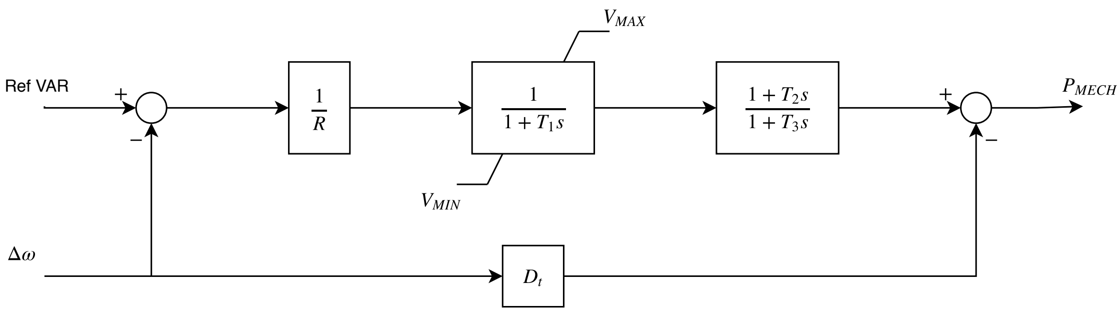

Figure 2: TGOV1 Block Diagram [5]

Table 12: TGOV1 Governor Parameters

TGOV1					
R	torT1	VMIN	VMAX	torT2	torT3
0.34	0.5	0	1	6	14

Table 13: Generic HYDR Governor Parameters

HYDR Generic							
SIGMA	TP	QV	KP	KI	TSM	LIMZDOT	TW
0.04	2.0	0	2.0	0.4	0.2	0.1	1.0

To represent a future-low inertia scenario, a mixture of energy sources have been added to each node using future predictions for the integration of renewables to the GB system as discussed in [6, 7]. This has been done by using the expected penetration percentages of different energy sources in 2020 in relation to the total power capacity at each node.

Table 14: 2020 Predicted Energy at Each System Node

Source	Node									
	1	2	3	4	5	6	7	8	9	10
CCGT	0.00%	82.23%	0.00%	0.00%	0.00%	0.00%	0.00%	*	*	4.62%
COAL	0.00%	0.00%	0.00%	76.11%	0.00%	0.00%	0.00%	*	*	9.91%
HYDR	15.20%	1.25%	50.05%	13.62%	0.00%	0.00%	0.00%	*	*	0.00%
NUCL	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	40.73%	*	*	28.07%
WIND	49.48%	16.52%	49.95%	2.17%	0.00%	89.36%	29.82%	*	*	0.00%
CONV	35.32%	0.00%	0.00%	8.11%	0.00%	10.64%	29.45%	*	*	57.41%
	11	12	13	14	15	16	17	18	19	20
CCGT	19.89%	43.59%	*	*	0.00%	61.67%	0.00%	39.42%	64.79%	0.00%
COAL	25.99%	0.00%	*	*	99.53%	31.61%	100%	60.58%	0.00%	0.00%
HYDR	0.00%	45.40%	*	*	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
NUCL	26.19%	9.33%	*	*	0.00%	0.00%	0.00%	0.00%	0.00%	100%
WIND	0.00%	1.68%	*	*	0.47%	0.00%	0.00%	0.00%	0.00%	0.00%
CONV	27.93%	0.00%	*	*	0.00%	6.72%	0.00%	0.00%	35.21%	0.00%
	21	22	23	24	25	26	27	28	29	-
CCGT	100%	100%	70.89%	*	100 %	71.22%	0.00%	88.38%	32.18%	-
COAL	0.00%	0.00%	19.90%	*	0.00%	28.78%	0.00%	11.62%	0.00%	-
HYDR	0.00%	0.00%	0.00%	*	0.00%	0.00%	0.00%	0.00%	0.00%	-
NUCL	0.00%	0.00%	0.00%	*	0.00%	0.00%	0.00%	0.00%	26.54%	-
WIND	0.00%	0.00%	9.22%	*	0.00%	0.00%	0.00%	0.00%	0.00%	-
CONV	0.00%	0.00%	0.00%	*	0.00%	0.00%	100.00%	0.00%	41.28%	-

To build a complete system, the existing HVDC projects in Great Britain are to be included with realistic power transfers. These are listed in the following paragraph and the transfer destinations have been modeled using Thevenin infinite buses. There are currently four HVDC links in operation in Great Britain as mentioned in [8] in which three are using LCC converter technology and one using VSC. The LCC projects include the HVDC Moyle, BritNed and HVDC Cross-Channel Currently and there is one VSC-HVDC link in operation named East West Interconnector however there are more projects being planned.

- HVDC Moyle is a 500MW link between Auchencrosh (Scotland) and Ballycronan more (Northern Ireland) consisting of two 250kV monopolar DC lines with 250MW capacity. These cables are both 63.5km in length with 55km submarine.

- BritNed is a 1000MW link between Grain (England) and Maasulakte (Netherlands) consisting of a 450kV bipole circuit with bundled DC cables. These cables span over 260km with 250 km submarine.

- The last LCC project, HVDC Cross-Channel, is a 2000MW link between Sellindge (England) and Mandarins (France) which is built from two 270kV bipole circuits each with 1000MW capacity.This is over a distance of 73km in which 46km are submarine.

- The East West Interconnector is a 100MW link between Shotton (North Wales) to Rush North

Beach (Ireland) and consists of one circuit beneath the Irish sea and spans across 261km with a DC voltage of 200kV. The updated model is shown in Figure 1.

3 System Modifications

The following points should be considered in relation to the changes from Strathclyde for the current GB model:

Note that the modified model built is based on 2015/2016 operating points and not a future energy scenario.

3.0.1 Steady-State

- Scotland changes summary:
  - Original Data: Beauly, Peterhead, Errochty, Denny, Neilston, Strathaven, Torness, Eccles
  - Updated Data : Beauly, Blackhillock, Peterhead, Kintore, Tealing, Errochty, Rothienorman, Elvanfoot, Windyhill, Denny, Longannet, Inverkip, Hunterston, Neilston, Strathaven, Torness, Eccles
  - Therefore there is an additonal 8 nodes in the Scottish region of the network therefore include in model.

- Load Flow issues:
  - Constant SVC's to get correct MVAr values in Artere - might sort out power flow difference between models.

- HVDC:
  - Additional HVDC included.

3.0.2 Dynamic

- Synchronous machine model parameters. Check these with current models.

Table 15: Updated Model Synchronous Machine Parameters

Gen Type	T'do (s)	T"do (s)	T'qo (s)	T"qo (s)	H	D	Xd (pu)
CCGT	6.5	0.035	1.25	0.035	5.5	0	1.65
CHP	6.5	0.035	1.25	0.035	7	0	1.65
Coal	6.5	0.035	1.25	0.035	5	0	1.65
Nuclear	6.5	0.035	1.25	0.035	4	0	1.65
Hydro	7.7	0.1	*	0.2	3	0	0.8535
Pumped Storage	7.7	0.1	*	0.2	3.5	0	0.8535
Unspecified	6.5	0.035	1.25	0.035	7	0	1.65
	Xq (pu)	X'd (pu)	X'q (pu)	X"d=X"q (pu)	Xl (pu)	S(1.0) (pu)	S(1.2) (pu)
CCGT	1.65	0.275	0.65	0.185	0.15	0.193333	0.6674333
CHP	1.65	0.275	0.65	0.185	0.15	0.193333	0.6674333
Coal	1.65	0.275	0.65	0.185	0.15	0.193333	0.6674333
Nuclear	1.65	0.275	0.65	0.185	0.15	0.193333	0.6674333
Hydro	0.55	0.25	*	0.15	0.1	0.1	0.3
Pumped Storage	0.55	0.25	*	0.15	0.1	0.1	0.3
Unspecified	1.65	0.275	0.65	0.185	0.15	0.193333	0.6674333

- AVR:
  - ST1A with IEEEST PSS to compare with current ST1A model being used (26 nodes use this AVR) herefore compare models/parameters
  - ESAC1A (11 nodes use this AVR) therefore investigate ESAC1A excitation.
  - Note that both of these model parameters are from IEEE standards.

Table 16: Updated Model ST1A Parameters

ST1A									
UEL	VOS	TR (s)	VIMAX (pu)	VIMIN (pu)	TC (s)	TB (s)	TC1 (s)	TB1 (s)	KA
1	1	0.02	999	-999	1	1	0	0	210
TA (s)	VAMAX (pu)	VAMIN (pu)	VRMAX (pu)	VRMIN (pu)	KC	KF	TF (s)	KLR	ILR
0	999	-999	6.43	-6	0.038	0	0.01	4.54	4.4

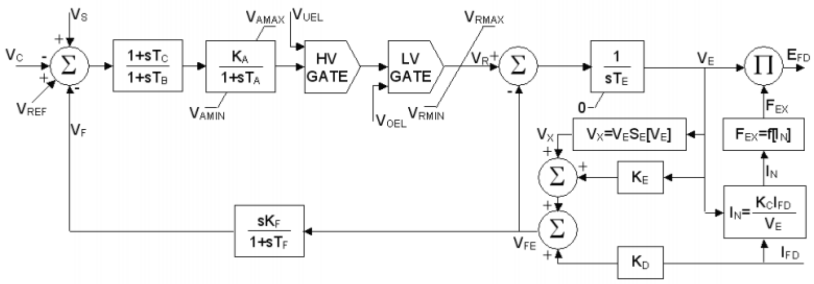

Figure 3: AC1A

Table 17: Updated Model AC1A Parameters

AC1A									
TR (s)	TB (s)	TC (s)	KA	TA (s)	VAMAX (pu)	VAMIN (pu)	TE (s)	KF	TF (s)
0	0	0	400	0.02	14.5	-14.5	0.8	0.03	1
KC	KD	KE	E1	SE(E1)	E2	SE(E2)	VRMAX	VRMIN (pu)	- (pu)
0.2	0.38	1	3.14	0.03	4.18	0.1	6.03	-5.43	-

- Governor:
  - TGOV1 is already in model so compare models/parameters.
  - Models for GAST and HYGOV (or similar) to compare to IEEE models and include in

Table 18: Updated Model TGOV1

TGOV1							
Gen Type	R	T1 (s)	VMAX	VMIN	T2 (s)	T3 (s)	Dt
Coal	0.04	0.5	0.85	0.4	1.5	5	0

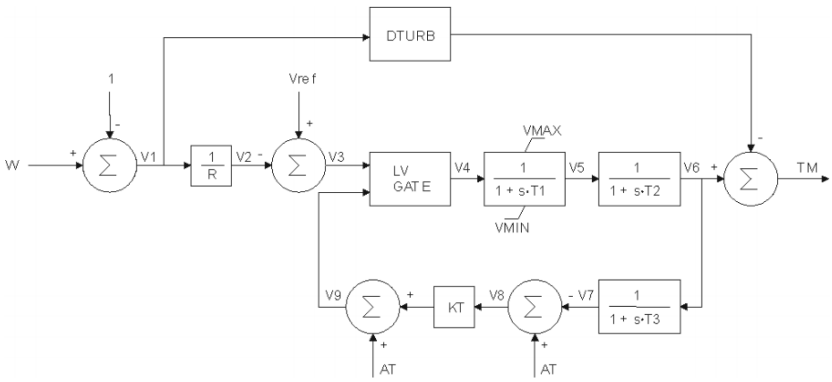

Figure 4: GAST

Table 19: Updated Model GAST Parameters

GAST									
Gen Type	R	T1	T2	T3	AT	KT	VMAX	VMIN	Dturb
CCGT	0.04	0.4	0.1	3	1	2	0.85	-0.05	0

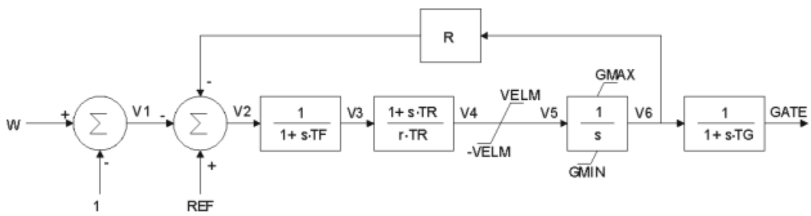

Figure 5: HYGOV

Table 20: Updated Model HYGOV Parameters

HYGOV												
Gen Type	R	r	Tr	Tf	Tg	VELM	GMAX	GMIN	TW	At	Dturb	qNL
Hydro	0.04	0.2	4	0.05	0.5	0.167	1	0	1.5	1.2	0	0.08

- SVC/Shunt:
  - SVC PSSE dynamic models - Should be fine using RAMSES.
  - Switch shunts used on 18 nodes - capacitor switching models?
- HVDC Links
  - HVDC Moyle, Britned and Anglo-French Interconnectors have been modelled as lines connected to -ve loads.
  - HVDC Models are generic.
  - VSC East-West interconnector model used.
  - New models includes the LCC West Coast connector and the VSC East Coast HVDC

4 Communication system (BT 21CN)

4.0.1 GB communication map

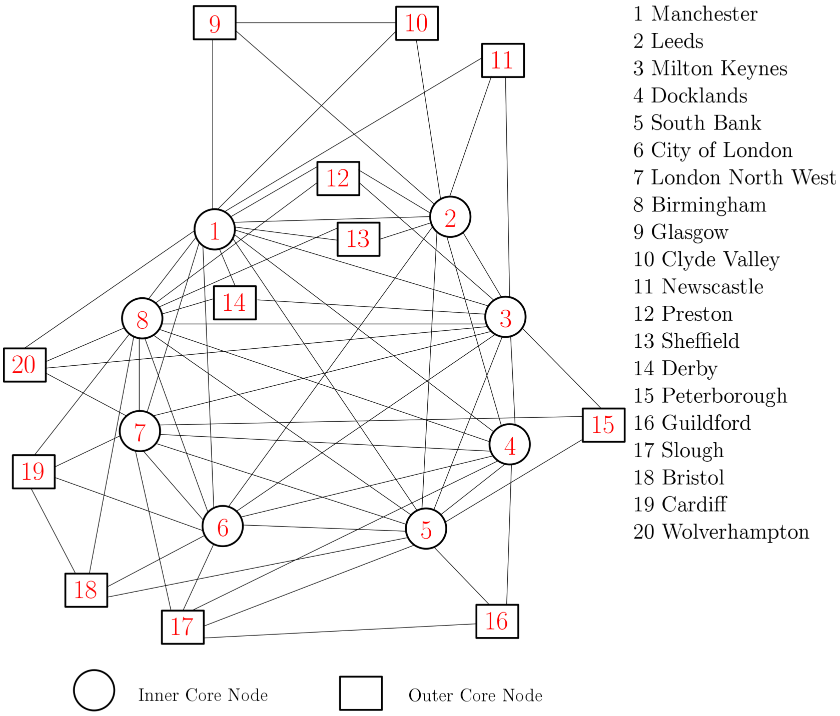

Figure 6: GB Communication Map

4.0.2 Table of communication delays between representative cities

Table 21, 22 is calculated from MATLAB script: Delay_BT_UK.m [1].

Table 21: GB Cities Communication Delay in ms (1)

	1. M	2. LS	3. MK	4. E	5. SE	6. EC	7. NW	8. B	9. G	10. ML
1. Manchester	0	60	61	62	62	62	62	61	62	62
2. Leeds	60	0	61	61	61	61	61	61	62	62
3. Milton Keynes	61	61	0	61	61	61	60	61	123	123

[1] The script can be downloaded at: https://zenodo.org/record/3408186#.XX0_ki2B01J

4. Docklands	62	61	61	0	60	60	60	61	123	123
5. South Bank	62	61	61	60	0	60	60	61	123	123
6. City of London	62	61	61	60	60	0	60	61	123	123
7. London N.W.	62	61	60	60	60	60	0	61	123	123
8. Birmingham	61	61	61	61	61	61	61	0	122	122
9. Glasgow	62	62	123	123	123	123	123	122	0	60
10. Clyde Valley	62	62	123	123	123	123	123	122	60	0
11. Newcastle	61	61	62	123	123	123	123	122	123	123
12. Preston	60	61	61	122	122	122	122	61	122	122
13. Sheffield	60	60	122	122	122	122	122	61	122	122
14. Derby	61	121	61	122	122	122	122	60	122	122
15. Peterborough	122	122	60	121	61	121	61	121	183	183
16. Guildford	122	122	121	60	60	121	121	121	184	184
17. Slough	122	122	121	60	60	60	60	121	183	183
18. Bristol	122	122	121	121	61	61	121	61	184	184
19. Cardiff	123	123	122	121	121	61	61	61	184	184
20. Wolverhampton	61	121	61	122	122	122	61	60	122	122

Table 22: GB Cities Communication Delay in ms (2)

	11. NE	12. PR	13. S	14. D	15. P	16. GU	17. SL	18. B	19. C	20. W
1. Manchester	61	60	60	61	122	122	122	122	122	61
2. Leeds	61	61	60	121	122	122	122	122	123	121
3. Milton Keynes	62	61	122	61	60	121	121	121	122	61
4. Docklands	123	122	122	122	121	60	60	122	121	122
5. South Bank	123	122	122	122	61	60	60	61	121	122
6. City of London	123	122	122	122	121	121	60	61	61	122
7. London N.W.	123	122	122	122	61	121	60	121	61	61
8. Birmingham	122	61	61	60	122	121	121	61	61	60
9. Glasgow	123	122	122	122	184	184	183	183	183	122
10. Clyde Valley	123	122	122	122	184	184	183	183	183	122
11. Newcastle	0	121	121	122	122	183	183	183	183	122
12. Preston	121	0	121	121	122	182	182	122	122	121
13. Sheffield	121	121	0	121	183	182	182	121	122	121
14. Derby	122	121	121	0	121	182	182	121	121	121
15. Peterborough	122	122	182	121	0	121	121	122	122	121
16. Guildford	183	182	182	182	121	0	60	121	182	182
17. Slough	183	182	182	183	121	60	0	121	121	121
18. Bristol	183	122	121	121	122	121	121	0	60	121
19. Cardiff	183	122	122	121	122	182	121	60	0	122
20. Wolverhampton	122	121	121	121	121	182	121	121	121	0

References

[1] M. Belivanis and K.R.W.Bell, “Representative GB Network Model.” Internal Report in the Dep. Electronic and Electrical Engineering, University of Strathclyde, Glasgow, 2011.

[2] L. Shen, “Model Integration and Control Interaction Analysis of AC/VSC HVDC System,” *[Thesis]. Manchester, UK: The University of Manchester; 2015.*, 2015.

[3] P. Pourbeik, A. Ellis, Y. Kazachkov, E. Muljadi, J. Senthil, and D. Davies, “Generic Stability Models for Type 3 & 4 Wind Turbine Generators for WECC,” 2013.

[4] PES, “IEEE Recommended Practice for Excitation System Models for Power System Stability Studies,” *IEEE Std 421.5-2005 (Revision of IEEE Std 421.5-1992)*, vol. 2005, no. April, pp. 1–85, 2006.

[5] IEEE PSDP, “Dynamic Models for Turbine-Governors in Power System Studies,” p. 117, 2013.

[6] L. P. Kunjumuhammed, B. C. Pal, and N. F. Thornhill, “A test system model for stability studies of UK power grid,” in *2013 IEEE Grenoble Conference PowerTech, POWERTECH 2013*, pp. 1–6, 2013.

[7] “UK Future Energy Scenarios,” *National Grid*, September 2012.

[8] “Summer outlook report 2018,” *National Grid*, April 2018.