Modified Version of the New England Test System

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1. INTRODUCTION

This report presents the data of the New England test system, including an LCC-HVDC link.

1.1 Preliminaries

The New England Test System[1] is modified to include an HVDC link as done by Kiliç and Ayan[2–4] and Sayah and Hamouda[5]. Figure 1 presents the single line diagram of the modified system. The AC transmission line between nodes 14 and 4 of the original system was replaced with a DC link (bus 14 is a rectifier bus and bus 4 is an inverter bus). Loads are modeled as constant power for AC-DC OPF and small-signal analysis. Generator 39 is considered the slack one.

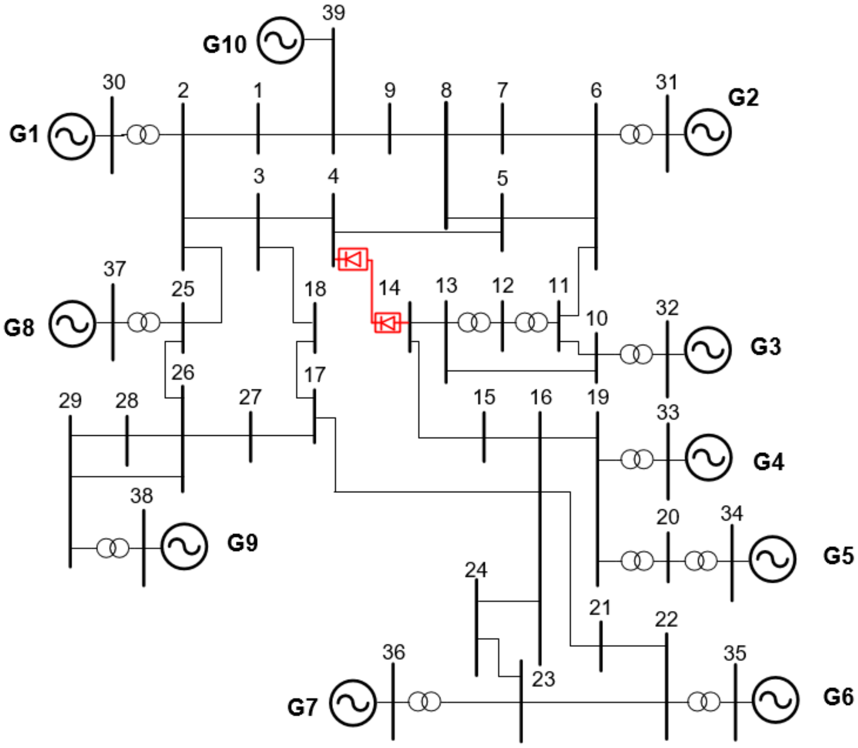

Figure 1 – One-line diagram of the modified New England test system.

2. AC POWER SYSTEM DATA

2.1 Base

Data are given on 100 MVA and 60 Hz base.

2.2 Loads[1]

Table 1 – Loads

Node	P_{Lk} (MW)	Q_{Lk} (Mvar)	Node	P_{Lk} (MW)	Q_{Lk} (Mvar)
1	0	0	21	274	115
2	0	0	22	0	0
3	322	2.4	23	247.5	84.6
4	500	184	24	308.6	-92.2
5	0	0	25	224	47.2
6	0	0	26	139	17
7	233.8	84	27	281	75.5
8	522	176	28	206	27.6
9	0	0	29	283.5	26.9
10	0	0	30	0	0
11	0	0	31	9.2	4.6
12	7.5	88	32	0	0
13	0	0	33	0	0
14	0	0	34	0	0
15	320	153	35	0	0
16	329	32.3	36	0	0
17	0	0	37	0	0
18	158	30	38	0	0
19	0	0	39	1104	250
20	628	103	--	--	--

2.3 Transmission Lines

Tables 2 and 3 present the transmission line data and transformers data[1]. Thermal limits were defined as 1300 MVA for all power system branches.

Table 2 – Transmission line data

From	To	r_{ij} (pu)	x_{ij} (pu)	b_{ij}^{sh} (pu)
1	2	0.0035	0.0411	0.6987
1	39	0.001	0.025	0.75
2	3	0.0013	0.0151	0.2572
2	25	0.007	0.0086	0.146
3	4	0.0013	0.0213	0.2214
3	18	0.0011	0.0133	0.2138
4	5	0.0008	0.0128	0.1342
5	6	0.0002	0.0026	0.0434
5	8	0.0008	0.0112	0.1476
6	7	0.0006	0.0092	0.113
6	11	0.0007	0.0082	0.1389
7	8	0.0004	0.0046	0.078
8	9	0.0023	0.0363	0.3804
9	39	0.001	0.025	1.2
10	11	0.0004	0.0043	0.0729
10	13	0.0004	0.0043	0.0729
13	14	0.0009	0.0101	0.1723
14	15	0.0018	0.0217	0.366
15	16	0.0009	0.0094	0.171
16	17	0.0007	0.0089	0.1342
16	19	0.0016	0.0195	0.304
16	21	0.0008	0.0135	0.2548
16	24	0.0003	0.0059	0.068
17	18	0.0007	0.0082	0.1319
17	27	0.0013	0.0173	0.3216
21	22	0.0008	0.014	0.2565
22	23	0.0006	0.0096	0.1846
23	24	0.0022	0.035	0.361
25	26	0.0032	0.0323	0.513
26	27	0.0014	0.0147	0.2396
26	28	0.0043	0.0474	0.7802
26	29	0.0057	0.0625	1.029
28	29	0.0014	0.0151	0.249

Table 3 – Transformers data

From	To	r_{ij} (pu)	x_{ij} (pu)	a_{ij}^0 (tap)	a_{ij}^{min}	a_{ij}^{max}
12	11	0.0016	0.0435	1.006	0.9	1.1
12	13	0.0016	0.0435	1.006	0.9	1.1
6	31	0	0.025	1.07	0.9	1.1
10	32	0	0.02	1.07	0.9	1.1
19	33	0.0007	0.0142	1.07	0.9	1.1
20	34	0.0009	0.018	1.009	0.9	1.1
22	35	0	0.0143	1.025	0.9	1.1
23	36	0.0005	0.0272	1	0.9	1.1
25	37	0.0006	0.0232	1.025	0.9	1.1
2	30	0	0.0181	1.025	0.9	1.1
29	38	0.0008	0.0156	1.025	0.9	1.1
19	20	0.0007	0.0138	1.06	0.9	1.1

2.4 Generators Data[5]

For generation cost minimization, consider equation (1) and data from Table 4. For cost calculation, consider P_{Gk} in MW. Limits are given in MV/Mvar.

$$Cost = \sum_{k=1}^{ng} (a_k + b_k . P_{Gk} + c_k . P_{Gk}^2) \ \$/h \tag{1}$$

Table 4 – Generator data

Generator	a_k	b_k	c_k	P_{Gk}^{min}	P_{Gk}^{max}	Q_{Gk}^{min}	Q_{Gk}^{max}
30	0	6.9	0.0193	100.00	350.00	-1500.00	1500.00
31	0	3.7	0.0111	200.00	650.00	-1500.00	1500.00
32	0	2.8	0.0104	300.00	800.00	-1500.00	1500.00
33	0	4.7	0.0088	300.00	750.00	-1500.00	1500.00
34	0	2.8	0.0128	250.00	650.00	-1500.00	1500.00
35	0	3.7	0.0094	300.00	750.00	-1500.00	1500.00
36	0	4.8	0.0099	250.00	750.00	-1500.00	1500.00
37	0	3.6	0.0113	250.00	700.00	-1500.00	1500.00
38	0	3.7	0.0071	400.00	900.00	-1500.00	1500.00
39	0	3.9	0.0064	600.00	1200.00	-1500.00	1500.00

2.5 Generators Dynamic Data

Table 5 brings generators' data for dynamic simulation: it is considered a third-order model for generators and a first-order model for automatic voltage regulators[1].

Table 5 – Machine and Excitation system data

Gen	X_d	X_q	X'_d	H	D	T'_{d0}	K_A	T_A
30	0.1	0.069	0.031	42	0	10.2	5	0.06
31	0.295	0.282	0.0697	30.3	0	6.56	6.2	0.05
32	0.2495	0.237	0.0531	35.8	0	5.7	5	0.06
33	0.262	0.258	0.0436	28.6	0	5.69	5	0.06
34	0.67	0.62	0.132	26	0	5.4	40	0.02
35	0.254	0.241	0.05	34.8	0	7.3	5	0.02
36	0.295	0.292	0.049	26.4	0	5.66	40	0.02
37	0.29	0.28	0.057	24.3	0	6.7	5	0.02
38	0.2106	0.205	0.057	34.5	0	4.79	40	0.02
39	0.02	0.019	0.006	500	0	7	5	0.01

Conventional power system stabilizers derived from terminal speed are employed here. The structure is presented in equation (2), in which $T_w = 5\ seg$ and $nbl = 2$. The parameters are presented in Table 6. Generator 39 does not receive a PSS since it represents an equivalent system.

$$PSS_p(s) = K_p.\frac{(s.T_w)}{(1+s.T_w)}.\frac{\left(1+s\frac{\sqrt{\alpha_p}}{\omega_p}\right)^{nbl}}{\left(1+s\frac{1}{\omega_p.\sqrt{\alpha_p}}\right)^{nbl}} \tag{2}$$

Table 6 – Power System Stabilizers data

Gen	K_p	α_p	ω_p
30	32.58	9.9752	12.582
31	33.417	9.9691	13.61
32	29.218	9.9686	20.762
33	20.378	8.0703	27.935
34	19.998	9.9019	25.909
35	20.683	6.5638	28.549
36	23.773	9.4152	26.861
37	29.229	9.9727	13.75
38	21.847	2.3898	28.484
39	--	--	--

2.6 Nodal Voltages Limits for Optimal Power Flow

For solving the OPF, voltage magnitudes are constrained between 0.9 to 1.1 pu.

3. HVDC LINK DATA

3.1 Preliminaries

Figure 2 depicts the representation of a two-terminal HVDC link and the variables are defined in work developed by Sayah and Hamouda[5]: (i) V_{rk} and V_{ik} are the AC bus voltages at the transformer primaries of rectifier and inverter; (ii) t_{rk} and t_{ik} are the transformers tap ratios of the rectifier and inverter; (iii) V_{drk} and V_{dik} are the direct voltages at the terminals of the rectifier and inverter; (iv) I_{dk} denotes the direct current; (v) φ_{rk} and φ_{ik} are the power factor angles seen from the AC bus of the rectifier and inverter; (vi) P_{drk} and Q_{drk} are the active and reactive powers at rectifier side; (vii) P_{dik} and Q_{dik} are the active and reactive powers at inverter side; ($viii$) R_{dk} is the DC link resistance.

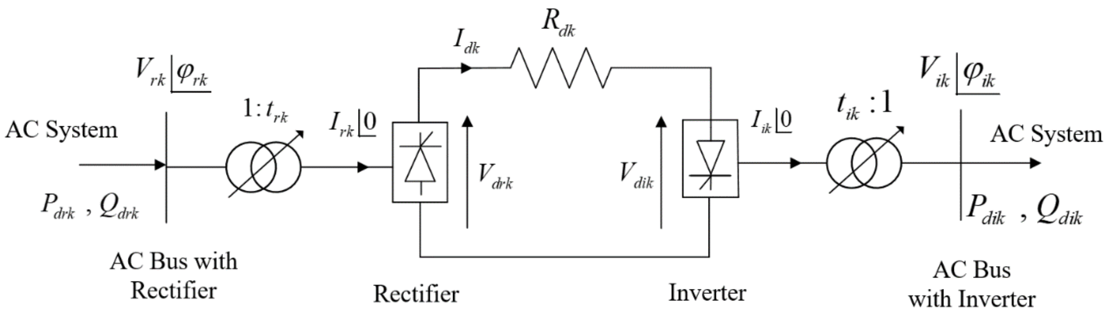

Figure 2 – Representation of a two-terminal HVDC link.

For dynamic studies, the HVDC link can be represented by an RL series circuit and the direct current I_{dk} can be kept constant at a reference value I_{ordk} through the current control loop depicted in Figure 3. This current control loop comprises the Current Control Amplifier (CCA) and the Voltage Controlled Oscillator (VCO). The CCA acts as a current regulator (Proportional Integral (PI) control action) that generates a signal to the VCO that controls the firing angle of the rectifier (α_k). Consider: (i) K_{Pk} and K_{Ik} the proportional and integral gains (CCA); (ii) T_k the time constant associated with the VCO.

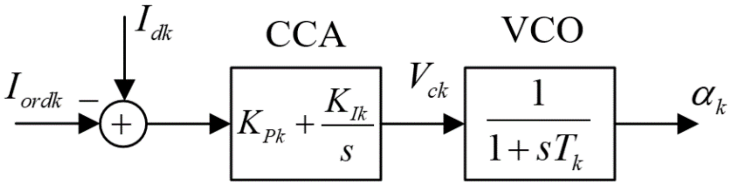

Figure 3 – Current control loop.

3.2 HVDC Link Data

The following data defines the HVDC link:

a) HVDC data (see Figure 2): (*i*) Rectifier at bus 14 and Inverter at bus 4; (*ii*) $X_{cr14} = 0.0459$ pu and $X_{ci4} = 0.0518$ pu; (*iii*) $R_{dk} = 0.001$ pu;

b) HVDC inductance: $L_k = 0.0107$ pu;

c) Current control loop (see Figure 3): (*i*) $K_{Ik} = 20$; (*ii*) $K_{Pk} = 35$; (*iii*) $T_k = 0.01$ sec.

Finally, Table 7 brings the limits for variables of the HVDC system[5].

Table 7 – HVDC variables limits

Variable	Lower	Higher
V_{dr} (pu)	1.00	1.50
V_{di} (pu)	1.00	1.50
t_r	0.85	1.15
t_i	0.85	1.15
α (º)	7.00	25.00
γ (º)	10.00	30.00
P_{dr} (pu)	0.10	1.50
Q_{dr} (pu)	0.00	1.00
P_{di} (pu)	0.10	1.50
Q_{di} (pu)	0.00	1.00
I_d (pu)	0.10	1.00

4. REFERENCES

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