

APPENDIX A: IEEE 14-BUS NETWORK DATA

Tables A1 and A2 reproduce the standard published IEEE 14-bus branch and bus data [20] used to construct the 14x14 Y-bus admittance matrix employed throughout Section 4 (100 MVA base). The complete Y-bus matrix is not tabulated because of space limitations; it can be reconstructed directly from Table A1. It provides the complete branch data required to reconstruct the IEEE 14-bus network admittance matrix used throughout this study.

Table A1. IEEE 14-bus branch data (100 MVA base). B is the total line charging susceptance (Y_{pq})

Branch	From-To	R (p.u.)	X (p.u.)	B (p.u.)	Type
1	1-2	0.01938	0.05917	0.05280	Line
2	1-5	0.05403	0.22304	0.04920	Line
3	2-3	0.04699	0.19797	0.04380	Line
4	2-4	0.05811	0.17632	0.03740	Line
5	2-5	0.05695	0.17388	0.03400	Line
6	3-4	0.06701	0.17103	0.03460	Line
7	4-5	0.01335	0.04211	0.01280	Line
8	4-7	0.0	0.20912	0.0	Transformer (tap 0.978)
9	4-9	0.0	0.55618	0.0	Transformer (tap 0.969)
10	5-6	0.0	0.25202	0.0	Transformer (tap 0.932)
11	6-11	0.09498	0.19890	0.0	Line
12	6-12	0.12291	0.25581	0.0	Line
13	6-13	0.06615	0.13027	0.0	Line
14	7-8	0.0	0.17615	0.0	Line
15	7-9	0.0	0.11001	0.0	Line
16	9-10	0.03181	0.08450	0.0	Line
17	9-14	0.12711	0.27038	0.0	Line
18	10-11	0.08205	0.19207	0.0	Line
19	12-13	0.22092	0.19988	0.0	Line
20	13-14	0.17093	0.34802	0.0	Line

Table A2 summarises the bus types, voltage set-points, generation, and load data used to initialise the network model.

Table A2. IEEE 14-bus bus data: generation, load, and voltage set-points (100 MVA base)

Bus	Type	V (p.u.)	Pgen (MW)	Qgen (MVar)	Pload (MW)	Qload (MVar)
1	Slack	1.060	232.4	-16.9	0.0	0.0
2	PV	1.045	40.0	42.4	21.7	12.7
3	PV	1.010	0.0	23.4	94.2	19.0
4	PQ	-	0.0	0.0	47.8	3.9
5	PQ	-	0.0	0.0	7.6	1.6
6	PV	1.070	0.0	12.2	11.2	7.5
7	PQ	-	0.0	0.0	0.0	0.0
8	PV	1.090	0.0	17.4	0.0	0.0
9	PQ (wind farm)	-	0.0	0.0	29.5	16.6
10	PQ	-	0.0	0.0	9.0	5.8
11	PQ	-	0.0	0.0	3.5	1.8
12	PQ	-	0.0	0.0	6.1	1.6
13	PQ	-	0.0	0.0	13.5	5.8
14	PQ	-	0.0	0.0	14.9	5.0

Although the standard IEEE 14-bus benchmark includes a 0.19 p.u. shunt capacitor at Bus 9, it was intentionally omitted from the present model to remain consistent with the implemented simulation framework and the reported base-case voltage ($V_{9_base} = 1.034$ p.u.; the base-case value with the standard shunt included is 1.055 p.u.). Reactive power injections in Table A2 for PV buses (2, 3, 6, 8) reflect the base-case load-flow solution used to initialise the Newton-Raphson solver at $t = 0$.

APPENDIX B: CONSOLIDATED MODEL AND CONTROLLER PARAMETERS

Table B1 summarises the parameters of the DFIG model, wind model, STATCOM, SVC, and Newton–Raphson solver used throughout the simulations.

Table B1. Consolidated DFIG, wind, STATCOM, SVC, and solver parameters used in all simulations

Category	Symbol	Value	Description
DFIG / wind turbine	Pr	penetration (%) x 100 MVA	Wind-farm rated capacity, scales with penetration level (e.g. 30 MW at 30% penetration; 50 MW at the 50% sensitivity bound)
DFIG / wind turbine	v _{ci}	3 m/s	Cut-in wind speed
DFIG / wind turbine	v _r	12 m/s	Rated wind speed
DFIG / wind turbine	v _{co}	25 m/s	Cut-out wind speed
DFIG / wind turbine	Q _t	4.0 MVar	Transformer magnetising reactive demand
DFIG / wind turbine	k _q	0.28	Stator reactive-demand coefficient
AR(1) wind model	tau	15 s	Turbulence time constant
AR(1) wind model	TI	0.08	Turbulence intensity (IEC 61400 Class B)
AR(1) wind model	T, dt	600 s, 0.5 s	Simulation horizon and time step (1200 steps)
STATCOM PI controller	K _p , K _i	2.0, 0.6	Proportional and integral gains (Eq. 7)
STATCOM PI controller	Q _{comp} limit	±20 MVar	Reactive power operating range, anti-windup back- calculation
SVC TCR model	T _{svc}	0.05 s	First-order lag time constant (Eq. 8)
SVC TCR model	K _{p,svc}	15	Proportional gain
SVC TCR model	Ramp limit	±10 MVar/s	Thyristor switching rate limit
SVC TCR model	Q limit	±20 MVar	Output magnitude clip (same range as STATCOM)
Newton-Raphson solver	Max iterations	8	Per time step
Newton-Raphson solver	Tolerance	10 ⁻⁵ p.u.	Power-mismatch convergence criterion
Wind-farm location	Bus	9	Wind-farm connection point (rated capacity per Pr row above)